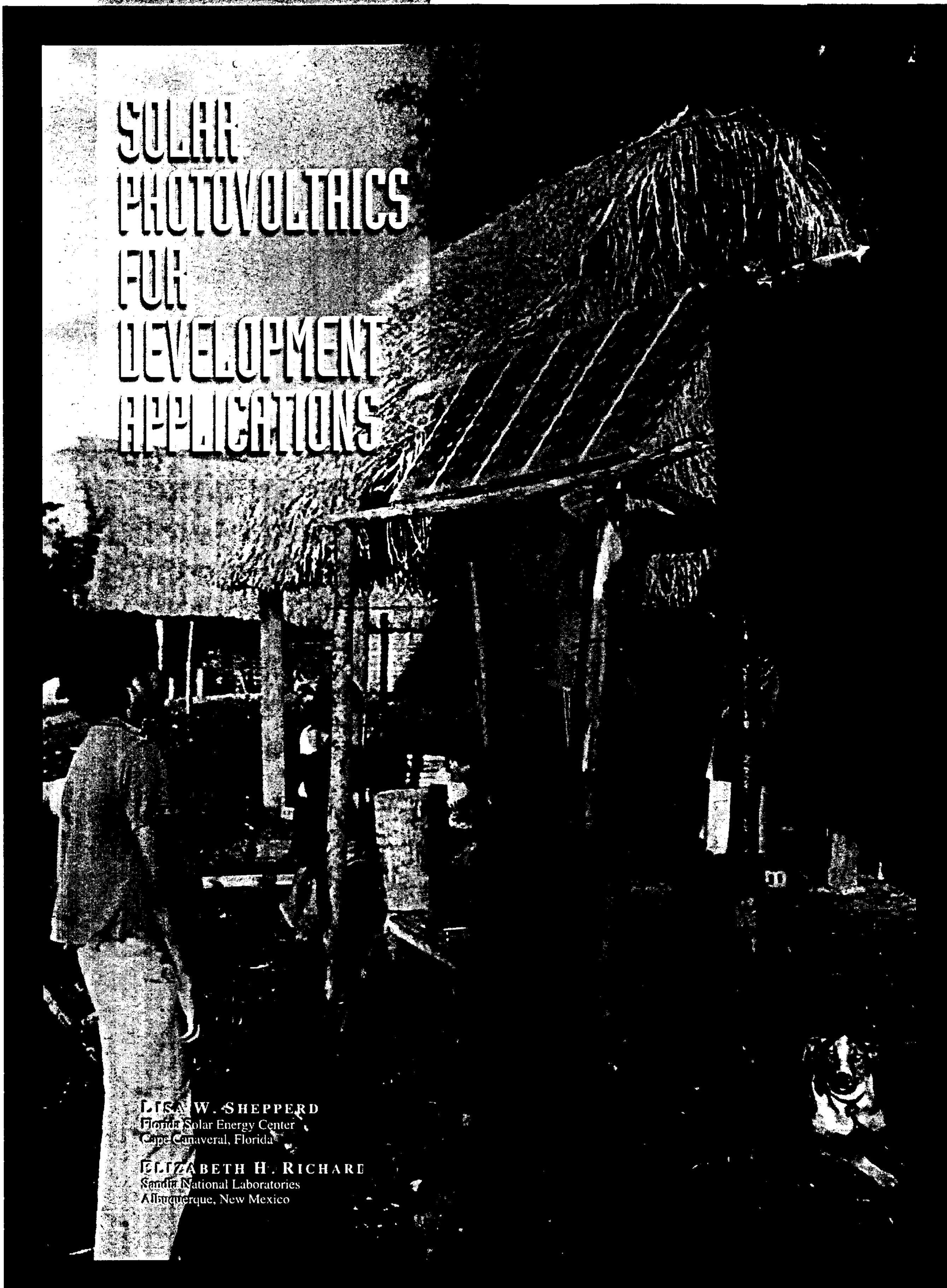

SOLAR PHOTOVOLTAICS FOR DEVELOPMENT APPLICATIONS

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U.S. DEPARTMENT OF ENERGY

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation. Please direct comments to Lisa Shepperd, Florida Solar Energy Center, 300 State Road 401, Cape Canaveral, FL 32920; or Elizabeth Richards, Department 6218, Sandia National Laboratories, Albuquerque, NM 87185-5800.

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COVER:

A Sirionó Indian erects a photovoltaic array to power lights and charge batteries in an encampment in northeastern Bolivia. Photo courtesy of Dr. Allyn Stearman, University of Central Florida.

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Solar Photovoltaics for Development Applications

SAND93-1642
Distribution Category 270
Unlimited Release
Printed August 1993

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Abstract

This document introduces photovoltaic technology to individuals and groups specializing in development activities. Examples of actual installations illustrate the many services supplied by photovoltaic systems in development applications, including water pumping, lighting, health care, refrigeration, communications, and a variety of productive uses. The various aspects of the technology are explored to help potential users evaluate whether photovoltaics can assist them in achieving their organizational goals. Basic system design, financing techniques, and the importance of infrastructure are included, along with additional sources of information and major U.S. photovoltaic system suppliers.

Acknowledgements

This document is the result of efforts by the Photovoltaics Design Assistance Center at Sandia National Laboratories and the Florida Solar Energy Center under contract to Sandia. The authors thank the following people for providing review and comments: Max Harcourt, Ron Pate, Mike Thomas, Ward Bower, Dave Hasti and Gary Jones (Sandia National Laboratories); Jim Dunlop, Danny Parker, and Gerard Ventre (Florida Solar Energy Center); Herb Wade (Asian Institute of Technology), Stephen Klein (Energy Consultant), John Rogers and Richard Hansen (Enersol Associates), John Ryan (International Fund for Renewable Energy and Energy Efficiency), Chris Rovero (Meridian Corporation), Larry Flowers (National Renewable Energy Laboratory), Ivan Azurdia Bravo and Pete Smith (National Rural Electrification Cooperative Association), Prasanna Pathirana (Power and Sun), Bill Howley and Rob Muhn (Siemens Solar Industries), Brady Bancroft and Joan Matranga (Solar Energy International), Tim Ball and Christy Holtz (Solar Engineering), Neville Williams (Solar Electric Light Fund), Jimmy Royer (Solener Inc.), Charles Gay (UNISUN), Tom Hall (U.S. Department of Energy), and Rick Sellers and Scott Sklar (U.S. Export Council for Renewable Energy). The editing and production assistance of Anne Van Arsdall and Peggy Valencia (Sandia National Laboratories) was crucial, as was the document design and layout talent of Craig Goldsmith at Subia. Special thanks go to the photovoltaic system suppliers and development organizations which supplied their photos and stories (presented and otherwise) for this document.

Preface

This document is intended to promote the knowledge and appropriate use of solar photovoltaic technology for development applications. It focuses on the services provided by photovoltaic-generated electricity and describes just a few of the thousands of photovoltaic installations which are providing basic services such as water pumping, lighting, and vaccine refrigeration in developing regions. This guide introduces the technology, discusses its applications and use, and directs you to additional sources of equipment and literature.

This document also illustrates why photovoltaic technology is especially well suited for use in developing rural regions of the world. Our examples of successful installations in remote areas are meant, in part, to encourage development specialists to consider the use of photovoltaics. Development organizations encompass a broad range of concerns and sizes ranging from small non-governmental and private non-profit organizations to large international alliances and government agencies. Although they may vary in structure, size, funding, and influence, these groups often share a common goal: to promote the intelligent, enduring, and equitable use of the earth's resources for the purpose of sustainable development. Photovoltaics can help achieve this goal.

The development terminology used in this document is derived in part from the United Nations report by the Brundtland Commission, *Our Common Future*, published in 1987. The term "development" refers to the political, economic, and social progress of a region; "developing countries" include the 122 still-industrializing nations in the world; "developed" or "industrialized" countries refer to the seven major world economies (including the United States, Canada, Japan, Australia, New Zealand, and the majority of Western Europe). Please refer to the GLOSSARY for additional definitions.

Solar Photovoltaics for Development Applications is one of several documents published by the Design Assistance Center to promote the appropriate use of photovoltaic technology. The Center is a national resource for technical information about renewable energy technologies. Established in 1984 as part of the U.S. Department of Energy's National Photovoltaics Program, the Center assures transfer of the technology base and encourages contact between potential users and suppliers of systems and components. Since 1987, the Center has also provided technical assistance on other renewable energy technologies in support of the U.S. Committee on Renewable Energy Commerce and Trade (CORECT). The Center is part of Sandia National Laboratories in Albuquerque, New Mexico, in the southwestern United States. Sandia is a multi-program research and development engineering laboratory operated for the U.S. Department of Energy.

The Design Assistance Center works collaboratively through contracts with other organizations in carrying out its mission. The Florida Solar Energy Center (FSEC) is a non-profit, research, testing, and educational institute established by the state legislature in 1974, and administrated by the Florida State University System. The Florida Solar Energy Center works with Sandia on a variety of projects involving photovoltaics. FSEC also specializes in energy conservation research for buildings and the refinement of solar hot water heating systems, among other energy topics. It is located in Cape Canaveral, Florida, in the southeastern United States.

"...The primary purpose of renewable energy projects in the developing world is not the promotion of renewable energy technology as such, but rather to meet the energy needs of the developing world in the most effective manner possible. When renewable energy technologies satisfy this criterion, they should obviously be used."

— GERALD FOLEY,
STOCKHOLM ENVIRONMENT INSTITUTE 1991

Contents

Introduction

Solar photovoltaic (PV) technology is an appropriate and cost-effective source of electricity for many applications in developing regions of the world. Photovoltaic systems bring people basic services and amenities, such as light, water, communications, power for businesses, and power for other productive uses in an environmentally sensitive manner.

ENERGY USE IN THE DEVELOPING WORLD

Developing countries now account for about 30% of global energy use; with continued economic growth they are projected to account for over one-half of the increase in global energy consumption over the next three decades. Approximately 75% of the population of the developing world (approximately two billion people) still lives without electricity. An expanding population with a growing desire for basic services (such as lighting, water, health care, and education) and an increasing appetite for consumer goods (such as radios, televisions, and other electrical appliances) puts heavy pressure on local governments to keep pace with the demand for electricity. However, government coffers frequently cannot afford the high cost of building and operating new centralized power plants and their related infrastructures, so people not served by existing power systems must find other means of fulfilling their energy needs.

People not served by a power grid often rely on fossil fuels like kerosene and diesel for many of their energy needs. Fossil fuels are often imported, and their use leaves economies vulnerable to global price fluctuations and disruptions in supply. Transporting these fuels to remote locations can be expensive and difficult, and their indiscriminate use can also be harmful to health and the environment. Maintenance of fossil-fuel-driven generators can also be problematic for people living in the developing world.

"...[P]roblems related to energy are closely connected to broader issues of economic and social development and international equity."
— BRUNDTLAND COMMISSION, 1987

SOLAR ENERGY

In contrast, solar energy (as well as other renewable energy technologies) is a comparatively clean and economical energy alternative that is not dependent on a foreign source of fuel. Many developing countries are located near the equator and have high levels of sunshine year-round, providing them with a free and abundant energy supply that is locally available. In some cases, sunshine may be a country's only domestic energy resource. Using photovoltaics to generate electricity from sunlight is simple, requires no moving parts, and has been proven reliable in tens of thousands of installations worldwide. Photovoltaics may also be the most cost-effective means of supplying basic services when its life-cycle costs are compared against typical alternatives, such as the use of kerosene and candles for lighting, or the expansion of existing power distribution networks.

Photovoltaic systems are especially well suited for use in rural areas where large populations remain isolated from existing power distribution networks. For example, in the Dominican Republic, Zimbabwe, Sri Lanka, and Honduras the cost-effectiveness of photovoltaics in areas beyond the reach of a power grid has led to the individual purchase of thousands of small photovoltaic lighting systems. The high reliability of photovoltaic systems also makes them suitable for use in urban areas which may already have some access to a centralized electric power source and distribution grid. In the city of San Salvador, for example, the effects of war and drought led to extreme fluctuations in the national power supply. To preserve its fragile vaccines, a grid-connected health clinic installed a photovoltaic refrigeration system for greater reliability.

The use of photovoltaic systems in rural areas may help stem migration to already overcrowded urban centers. In many cases, the lack of access to basic services and meager economic opportunities in the countryside encourage people to move to the cities in search of a better life. Photovoltaics can provide the power necessary for electric lighting, health clinics, television, and water pumping and can supply power for businesses and other productive uses in rural areas. When these things are available locally, the desire or necessity of moving to a city may be diminished. In the Dominican Republic, the rural *campesinos* delight in their dependable photovoltaic lighting systems, while their city-dwelling, grid-powered relatives deal with frequent and unpredictable power outages and inconsistent billing practices. Similarly, the Mexican government's promotion of photovoltaics for rural development stems partly from a desire to improve basic services and economic opportunities in rural areas in order to reduce migration to larger cities. However, it must be noted that other cases demonstrate the reverse: in areas of the Pacific Islands, for example, the advent of electricity has led some family members to migrate to cities in search of jobs and cash in order to purchase these new electric services and appliances.

MYTH: SOLAR IS "TOO EXPENSIVE"

There is a tendency to dismiss the use of solar-generated electricity because of its relatively high price per kilowatt-hour as compared to traditional sources of energy, especially grid-supplied electricity. However, the issue is not so much what solar electricity ***costs****, but rather what the service it provides is* ***worth*** *to the user.*

Rural households connected to power-supply grids in the developing world on average use only a small amount of electricity — generally just enough to power on the order of three lights and a television or radio for three to four hours per night. In most cases, the revenue from such small energy usage does not cover the actual costs of generating and distributing electricity from a conventional power plant, as the price paid for this service is frequently based on political factors instead of the true costs, which are often hidden by heavy government subsidies. In the Dominican Republic, for example, even though the price of electric service for households connected to the existing grid may be as little as $ 0.11 per kilowatt-hour (when available), this does not reflect the cost of stringing copper wire across the countryside to remote sites. If a home with a typical electric load (i.e., six kilowatt-hours per month) were located only one mile from the grid, it would cost the utility over $11.00 per kilowatt-hour[1] to provide electrical service. This means that since the true cost of providing grid service for small dispersed rural loads is prohibitively expensive, and since government subsidies are limited, large segments of the developing world remain without access to electricity.

Instead, rural populations rely on other energy sources such as kerosene and candles for lighting, auto batteries to run televisions, and dry-cell batteries for radios and cassette players, etc. Although these lighting and electricity sources can be purchased in small enough quantities to be affordable, rural households are actually paying very high prices for these basic services. Again, in the Dominican Republic, the average monthly combined price for these energy sources is on the order of $1.00 to $2.00 per kilowatt-hour; for dry-cell batteries people routinely pay from $30.00 to $60.00 per kilowatt-hour.

In contrast, a typical single-module photovoltaic system can supply these loads for about $ 0.75 per kilowatt-hour[2] — higher than prices traditionally paid for grid-supplied electricity, but lower than the actual costs of the alternatives. Thus, despite common perceptions, small photovoltaic systems offer a cost-effective alternative to these traditional energy sources. They provide superior, more reliable, and more convenient services for a life-cycle cost that is ***comparable to or less than what households are already paying****.*

[1] When amortized over a 30-year period at a 10% interest rate, assuming $7500.00 per mile of extension.

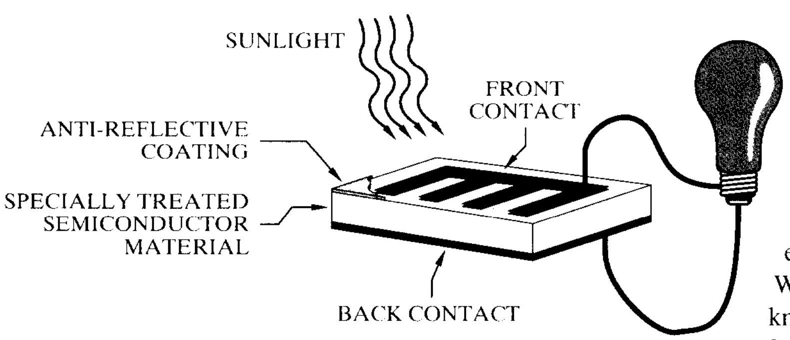
[2] Roughly assuming that a 50-watt system costs $700.00 installed and requires replacement of a $45.00 battery every 18 months over a 20-year system life. The average 5.5 peak sun hours available in the Dominican Republic are derated to 4 hours to account for various power losses in the system. All payments are in 1993 dollars.

What is photovoltaics?

Photovoltaics is the direct conversion of light into electricity. Some materials exhibit a property, known as the *photoelectric effect*, that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current results that can be used as electricity.

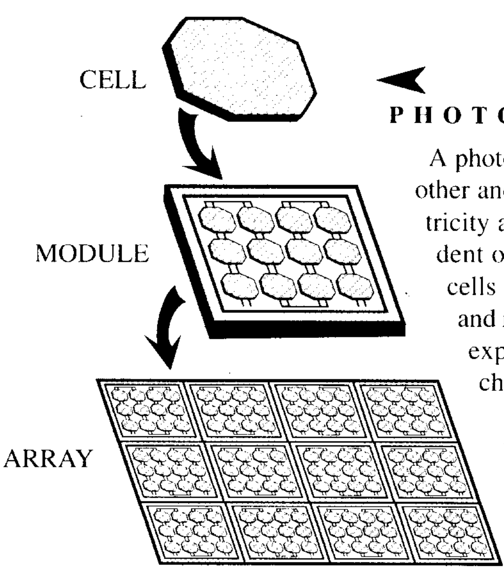
HOW DOES PHOTOVOLTAICS WORK?

You don't have to be an engineer to successfully install, operate, and maintain a photovoltaic system. Indeed, most people who use solar-powered (photovoltaic) calculators and watches don't fully understand their operation. However, a basic understanding of how photovoltaics works will enhance your ability to evaluate whether it is an appropriate technology for supplying the energy you need.



SOLAR CELLS

This diagram illustrates the operation of a basic photovoltaic cell, also called a solar cell. Solar cells are made of the same semiconductor materials (usually silicon) used in the microelectronics industry. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current — that is, electricity. This electricity can then be used to power a load, such as a light bulb or a water pump. A typical four-inch silicon solar cell produces about one-and-a-half watts of electricity in bright noon-time sunshine.



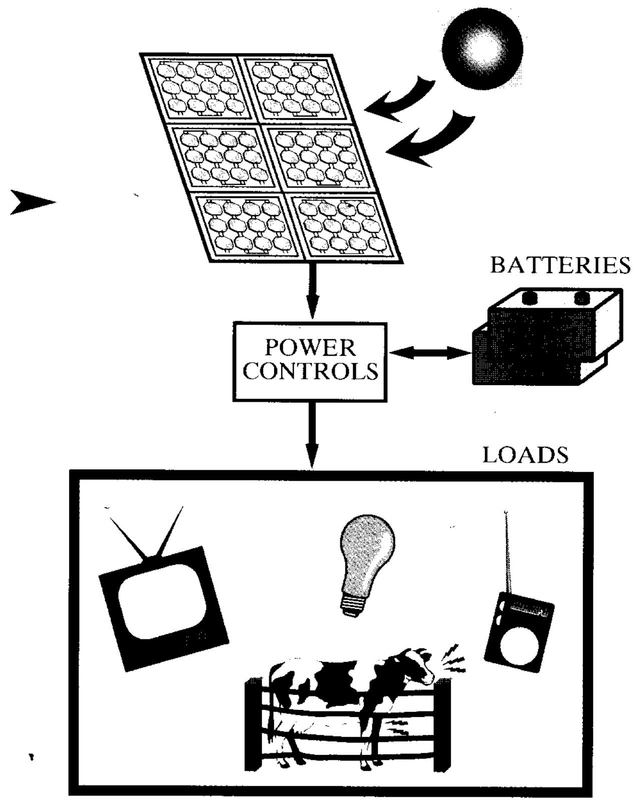
PHOTOVOLTAIC MODULES AND ARRAYS

A photovoltaic *module* consists of a number of solar cells electrically connected to each other and mounted in a support structure or frame. Modules are designed to supply electricity at a certain voltage (commonly 12 volts); the current produced is directly dependent on how much light strikes the module. The module structure protects the solar cells from the environment, and photovoltaic modules have proven to be very durable and reliable. They typically have ten-year manufacturer's warranties and much longer expected lifetimes in the field. (The terms *module* and *panel* are often used interchangeably, although panel sometimes refers to a few modules connected together.)

Although one module is often sufficient for many power needs, two or more modules can be wired together to form an *array*. In general, the larger the area of a module or array, the more electricity that will be produced. Photovoltaic modules and arrays produce direct-current (dc) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

PHOTOVOLTAIC SYSTEMS

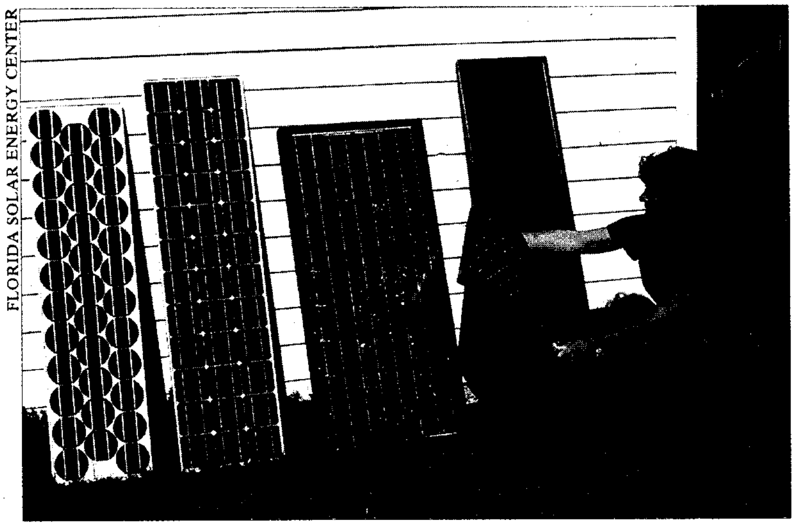
A photovoltaic array alone will not pump water or illuminate the night. A complete photovoltaic system consists of the module or array plus a number of other components, collectively known as the *balance of system* or BOS. These components vary depending on what types of service you want to provide and when you need it (day or night). It is a simple fact that when no light is available, photovoltaic modules cannot generate electricity. So, some form of energy storage is necessary to operate systems at night. Water can be pumped into a tank while the sun is shining and distributed by gravity when it is needed after dark. Lighting systems require the use of batteries, as do most other systems needed at night.



GROWTH OF AN INDUSTRY

The photoelectric effect was first noted by a French physicist, Edmund Bequerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, for which he later won a Nobel prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954. It was billed as a solar battery and was mostly just a curiosity as it was too expensive to gain widespread use. In the 1960s, the space industry made the first serious use of the technology to provide power aboard spacecraft. Through the space programs, the technology advanced, its reliability was established, and the cost began to decline. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications.

Today photovoltaics is a well-established, proven technology with a substantial international industrial network. As the industry grows, photovoltaic products are increasingly available throughout the developing world. In 1982, the industry shipped about 5 peak megawatts of photovoltaic modules; in 1992, nearly 60 peak megawatts were supplied, and today photovoltaic systems power everything from individual light bulbs to entire villages. As the market has increased, production facilities have been scaled up and manufacturing costs have declined. In the early 1980's, a user could expect to pay about $14 per rated peak watt of photovoltaics. By 1992, the price had fallen to less than half of that, and as the industry continues to expand, the price is expected to drop even further. (See page 3 for further discussion of the costs of photovoltaic systems.)



FLORIDA SOLAR ENERGY CENTER

(left to right): two mono-crystalline silicon modules (round and square-cut cells); a poly-crystalline silicon module; and two thin-film modules (rigid and flexible).

BASIC PHOTOVOLTAIC CELL MATERIALS AND MODULES

Although silicon is abundant — it is the basic material in beach sand — the process used to turn it into the high-purity semiconductor material required for solar cells is expensive. There are three main types of solar cells: mono-crystalline silicon (also known as single-crystal silicon), poly-crystalline silicon, and thin-film materials. The different cell technologies represent different approaches to trying to reduce the cost of photovoltaic-generated electricity.

The wafers for mono-crystalline *cells are sliced from a single crystal of pure silicon to a thickness similar to a fingernail. Photovoltaic cells made from this material have the highest efficiencies (the ratio of electricity produced per amount of sunlight), but are also expensive to manufacture.* Poly-crystalline *cell wafers are made from a cast block of silicon that has multiple crystals in it, and though they have some manufacturing advantages these cells are not as efficient as single-crystal cells.* Thin-film solar cells *are made in a vacuum chamber by depositing thin layers of semiconductor materials (usually amorphous silicon) onto a substrate, which ultimately becomes the front or back face of a module. Because thin films require very little semi-conductor material they have the potential for low-cost manufacturing. However, the thin-film materials on the market today have much lower operating efficiencies than either mono- or poly-crystalline cells.*

Most photovoltaic modules are known as flat-plate *modules. Modules made from both mono- and poly-crystalline silicon are assembled in a similar fashion. The cells are electrically connected to each other and are assembled into a module frame that provides structural support and environmental protection. Since poly-crystalline cells are slightly less efficient than single-crystal cells, poly-crystalline modules tend to be somewhat larger than mono-crystalline modules for a given power rating. Thin-film modules made on glass also look similar to crystalline modules. However, since thin-film cells have much lower efficiencies than the other two module types, they require substantially more area to produce a given amount of power. Commercially available modules typically range in power output from 1 to 110 watts, with thin films comprising the majority of the lower wattage modules (i.e. less than 10 watts).*

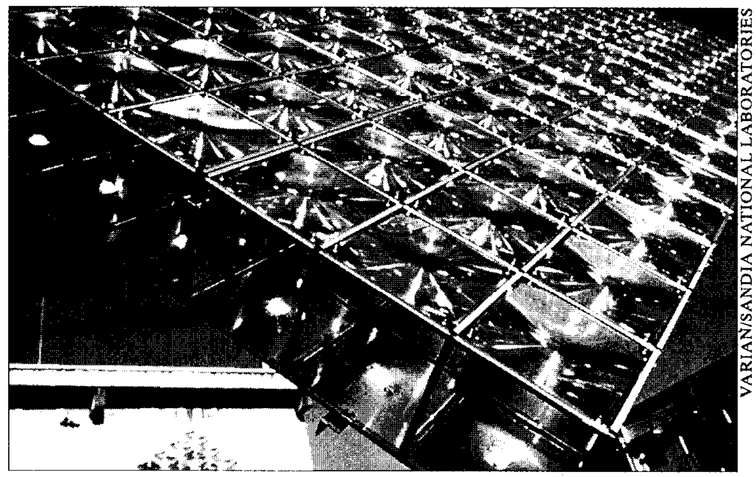
The reliability and durability of both mono- and poly-crystalline modules are well established, and most manufacturers offer at least a ten-year warranty. The reliability of thin-film modules is not as well established as that of crystalline modules, although improvements to the technology continue to be achieved. Products made with thin films deposited on sheets of metal or plastic are also entering the market, and their light weight and flexibility should prove to be an asset in many situations. In addition new photovoltaic technologies are under development and are expected to enter the marketplace in the future.

The costs per peak watt of photovoltaics for the various technologies vary, but are generally comparable. Potential buyers should check with suppliers to determine the most reliable and economical choice. Local supply conditions, including availability, shipping costs, and import duties are also important considerations.

A NOTE ABOUT CONCENTRATOR MODULES

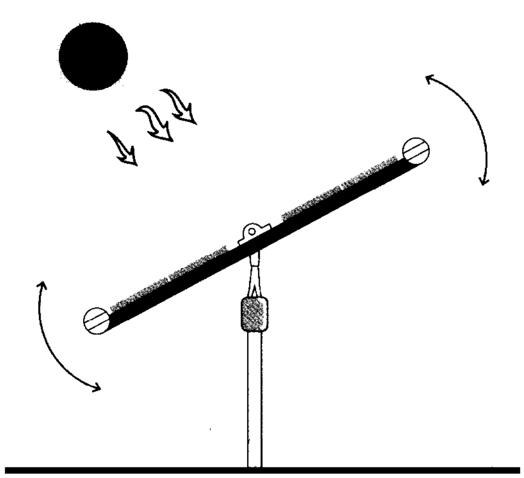
Another approach to reducing the cost of photovoltaic-generated electricity is concentrator photovoltaic module technology. Concentrator modules use plastic lenses to focus the sun's rays onto small photovoltaic cells placed near the focal point of the lens. This approach significantly reduces the amount of expensive solar cell material required to produce a given amount of electricity, although it adds to the complexity of the module. In addition, to accommodate the optics of the lenses, concentrator modules must be mounted on trackers that keep the module accurately aligned with the sun. Because of this added complexity and the requirement for accurate tracking, photovoltaic concentrator modules are generally used only in systems producing on the order of ten kilowatts or more. A substantial initial investment is required to purchase such large systems, so concentrators have not yet made significant headway in the commercial marketplace and represent less than one percent of all photovoltaic modules shipped annually.

Unlike flat-plate modules, concentrator modules generally use only the direct normal component of the sun's energy (that part which actually casts a shadow). They are usually not suitable for cloudy locations in which a large portion of the solar resource consists of diffuse light. However, concentrators typically have higher operating efficiencies which can partially compensate for this limitation.



Point-focus concentrator modules use individual lenses to focus sunlight onto discrete solar cells placed near the focal point of each lens facet.

Line-focus concentrator modules direct sunlight onto a line of solar cells.



TRACKERS

A tracker is a mechanical device that follows the sun on its daily sweep across the sky; mounting photovoltaic modules on a tracker keeps them facing the sun. Most photovoltaic modules (except concentrators) don't require tracking, but will collect more sunlight and therefore produce more electricity if they are always aimed at the sun. How much a tracker will enhance a system's performance depends on the application and local conditions. The choice to use a tracker hinges on the tradeoff between the cost of the tracker and the savings realized by using fewer photovoltaic modules to obtain a given amount of power. System simplicity is also a factor, as are wind conditions at the installation site.

Photovoltaics in action!

What can photovoltaics do for you? The following pages present a variety of stories about real people using photovoltaics to provide everyday services for their homes and communities, including water, lighting, health care, communications, and even refrigeration. Photovoltaic systems also supply electric power for many productive uses ranging from lighting in rural stores to electric fencing and roof-tile manufacture. For more information on the U.S. system suppliers mentioned here please refer to U.S. SUPPLIERS OF PHOTOVOLTAIC SYSTEMS FOR RURAL DEVELOPMENT at the end of this booklet.

WATER SUPPLIES

Water pumping is one of the simplest and most appropriate uses for photovoltaics. Irrigation, village water supplies, stock watering, domestic uses — photovoltaic-powered pumping systems meet a broad range of water needs. Most photovoltaic pumping systems have the added advantage of storing water for use when the sun is not shining, eliminating the need for batteries, enhancing simplicity, and reducing overall system costs.

Photovoltaic water pumping installations range in size and complexity. The irrigation system in Gambia (shown at left) uses sun trackers and electronic controls to increase system efficiency, reducing the number of required photovoltaic modules. The examples from Haiti and Mexico consist of very simple systems using stationary panels directly connected to small pumps.

Generally, you can plan to spend about $10.00 per peak watt of photovoltaics for the hardware and installation of a water pumping system (not counting site-specific items like shipping costs or import duties). The number of watts required (the size of the photovoltaic array) varies greatly and is dependent on how much water is needed, how high it must be lifted, and on the type of pump used. The amount and type of water storage also can affect the final cost. For example, a small photovoltaic pumping system with no storage that is capable of lifting 1300 gallons per day over a vertical distance of one meter costs about $200.00. In contrast, a large village water supply system capable of delivering 3000 gallons per day over a vertical distance of 60 meters costs in the neighborhood of $10,000.00. (Note: neither of these examples includes the costs of shipping nor import duties, and costs will vary with local conditions.)

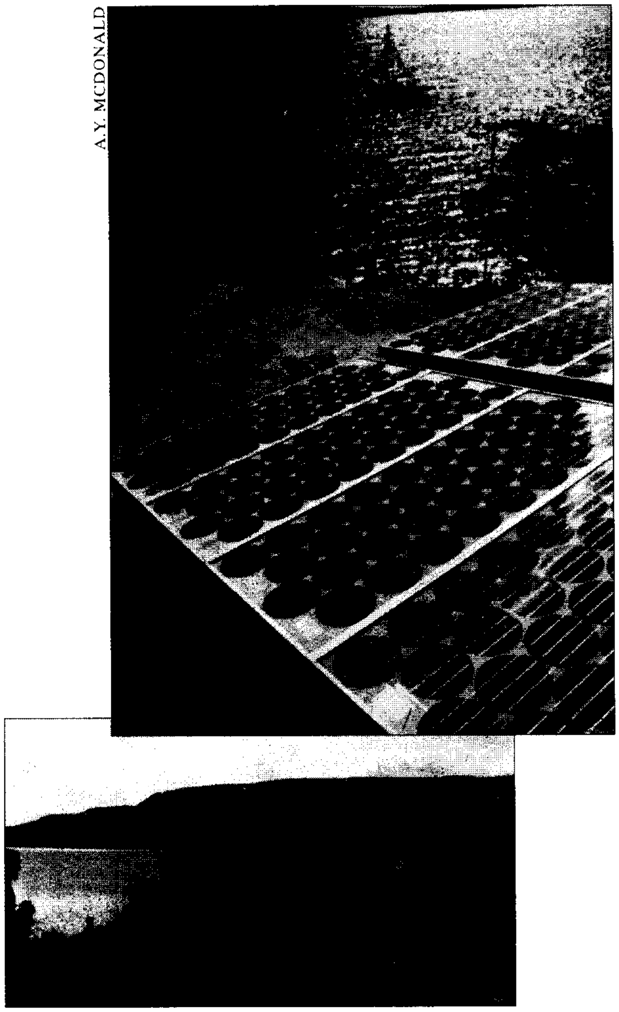
SUNWIZE ENERGY SYSTEMS

▲ This couple is standing in front of their village's water pumping system, located at a YMCA camp in Penjemu, Gambia. After decades of drought, Penjemu's old-fashioned hand-dug wells dried up, crops failed, and the village lost most of its inhabitants to larger cities. In 1990, the YMCA became involved in the government's efforts to lure the city-dwellers back to their old agricultural ways. In Penjemu, a new 30-meter well was dug. Then, in a joint effort involving the YMCA, Sunwize Energy Systems, and the local villagers, a four-kilowatt photovoltaic-powered pumping system was installed. The photovoltaic panels are mounted on trackers and power a three-horsepower pump. A YMCA engineer who lives in Penjemu trained four villagers in basic solar pump operation and maintenance. Now this water source dispenses up to 30,000 gallons per day to irrigate the villagers' fields and fill their water jugs. As of the end of 1992, no significant gaps in the water supply had been reported. In addition to pumping water, the system recharges a few small batteries, which power the only communication in town — a short-wave radio. Local Contact: James Gomez, President, YMCA of Gambia, Kanifing South, P.O. Box 421, Banjul, Gambia • fax 220-92866. System Supplier: Sunwize Energy Systems, Inc.

SOLAR SALES PTY. LTD.

This photovoltaic-powered water pumping system in northwestern Kenya serves 50 to 100 Pokot tribal members and 250 cattle. The tribe lives in an extremely sunny, remote desert area, only 200 miles north of the equator. They chose to "go solar" for stock irrigation in 1990, after a government representative presented their water pumping options. They decided against using diesel generators because, in addition to the associated cost and maintenance, it is difficult to get fuel to this isolated site. Solar power turned out to be a more sensible and cost-effective alternative. Two kilowatts of photovoltaic modules are mounted on trackers, providing power to pump about 1000 gallons per day into a communal trough. The system was designed for reliability and minimum maintenance as the nearest service center is in Nairobi, a two-day drive away. Tribal members helped with installation by building safety fences, digging holes, and carrying materials. The tribe is currently saving funds to purchase a large storage tank so that more stock can be watered. Local Contact: Mr. Vincent Loh, Total Solar Kenya Ltd., Nairobi • phone 254-2-822920. System Supplier: John S. Hall, Solar Sales Pty. Ltd. (Solarex Distributor), 97 Kew St. Welshpool, Western Australia • phone 619-3622111 • fax 619-3623231.

A.Y. MCDONALD



This system provides water for the 2000 inhabitants of Baie de Henne, a small town located along the arid Caribbean coast of northwestern Haiti. Prior to obtaining the photovoltaic pumping system, the town's people obtained their water from a spring on the beach, accessible only by climbing down a 30-foot cliff at the end of town. At low tide the water was good, but at high tide the sea water would flow into the pool and make it too salty to drink. In 1982, the spring was enclosed in concrete to keep the salt water out, and a 10,000-gallon storage tank was built on top of the cliff. Eight-hundred watts of photovoltaic modules mounted on top of the storage tank power a pump that keeps it filled from the spring below, and plastic pipes carry water by gravity to public water fountains located in town. The system was installed using local talent guided by CARE and U.S. Agency for International Development engineers. Based on the success of this system, eleven similar systems were installed in the Artibonite Valley, serving over 20,000 Haitians. Local Contact: Douglas Clark, CARE, P.O. Box 15546, Petion-Ville, Haiti • phone 509-57-53-58 • fax 509-57-72-20. System Supplier: A.Y. McDonald.

This system provides water for livestock, crops, and domestic use on a ranch located in the coastal state of Quintana Roo on the Yucatan Peninsula, Mexico. The photovoltaic system was installed in 1981, after the rancher had given up on both a windmill, due to lack of replacement parts, and a diesel engine-driven pump, due to the absence of skilled maintenance providers. About 500 watts of photovoltaic panels are ground-mounted on support structures made from small tree branches. A manually operated switch allows the photovoltaic array to provide power to either of two 1/2-horsepower pumps — one pump lifts water from a hand-dug well to a stone storage tank, and the other is used to boost pressure in the irrigation and water supply pipes on the ranch. A year after the initial installation, the rancher purchased a second photovoltaic array to pump water for stock at another well on the ranch. Local Contact: Miguel Alonso, Akamul, Quintana Roo, Mexico (no phone). System Supplier: A.Y. McDonald.

LIGHTING AND RESIDENTIAL POWER

Photovoltaic lighting systems provide clean, reliable light. In many parts of the developing world, people hold little hope of obtaining grid-supplied electricity in their foreseeable future. In these areas, light usually comes from candles, kerosene or paraffin lamps, or conventional battery-powered fixtures and flashlights. Photovoltaics can be a more economical choice than these sources while at the same time providing more light, higher quality light, and no smoke or fumes. A single electric light can extend working and recreation hours in both homes and businesses, and the same photovoltaic system that provides household lighting may also power other small residential appliances, such as radios and televisions, even blenders.

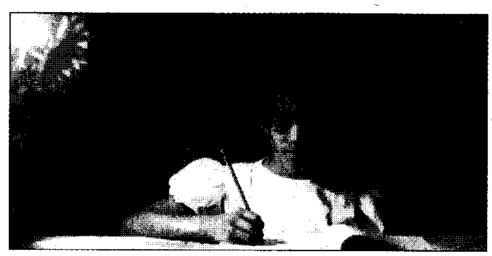
The power supplied by the photovoltaic systems shown in the following examples is only a fraction of the power demand of a typical household in the industrialized world where people take for granted the availability of virtually unlimited grid-supplied electricity and light-on-demand. The cost of supplying similar unlimited service to an individual home using photovoltaics is expensive relative to using existing central-station power and is far beyond the means of most people in developing areas. However, the difference between having no electricity at all and having a very small supply of it is much more profound than the difference between having a small and a large supply. Access to even a small amount of electric light can have a very big effect on day-to-day life.

Even where extending the power supply grid is possible, typical homes in developing areas have such minimal power needs that a photovoltaic system is often less expensive than the corresponding grid extension (see page 3, MYTH: SOLAR IS "TOO EXPENSIVE"). In some areas of Brazil and Mexico, for example, utility companies are installing small photovoltaic systems on individual homes as a less costly alternative to extending the grid for rural electrification.

Photovoltaic lighting systems require batteries because they operate at night when no sunlight is available. These systems often include some type of controller, either a manual control box or an electronic device, to protect the battery from being over-charged or over-discharged. To make best use of the photovoltaic system, the use of efficient light bulbs, usually fluorescent, is very important, as is a source for replacement bulbs. The types of batteries used in these small residential systems vary. Deep-discharge batteries are generally the best option from a life-cycle cost perspective; however, in remote rural areas locally-made car batteries are often the only type available (although they require fairly frequent replacement). In some instances, portable photovoltaic-powered lanterns may be the simplest option; several companies offer these and other pre-packaged lighting systems as well.

The cost of a photovoltaic lighting system depends on its size and complexity. For example, in the Dominican Republic, a typical 30- to 50-watt system with 5 lights costs between \$500 and \$700 installed and requires the replacement of a \$45 automobile battery about every 18 months. The prices of portable photovoltaic lanterns with 2 to 10 watts of photovoltaics typically range from \$100 to \$300. The financial section of this document discusses how these options can be made affordable in a developing area.

ENERSOL ASSOCIATES



ELECTRIC LIGHT IS SUPERIOR TO THAT SUPPLIED BY CANDLES OR KEROSENE

These photos illustrate the difference in the quality of light supplied by a photovoltaic system versus that provided by candles or kerosene. It is not hard to see why this girl in the Dominican Republic is more inclined to study at night now that her family has a photovoltaic system. In addition to being brighter, her new light can be placed in the best location for reading (such as above and behind), whereas placement of the candle is limited.

SANDIA NATIONAL LABORATORIES

This photovoltaic lighting system is one of many installed in rural areas of Honduras not served by an electric grid. Located at the home of a coffee farmer near the remote village of La Aradita, the system consists of one 48-watt photovoltaic panel, a locally manufactured car battery, and a manually operated control box. Originally the sýstem powered seven low-wattage lights distributed strategically throughout the home. As part of the installation process, the family was briefed on the proper operation and maintenance of their system, and later were able to rearrange the original lights, adding an additional one along with a television and a radio. Financing made it possible for the family to purchase this system. This was one of the first of over fifty systems installed in Honduras during the first year of a cooperative effort by the U.S. Peace Corps, Enersol Associates, and Sandia National Laboratories' Design Assistance Center. Photovoltaic systems now serve 15 businesses, 31 homes, and 5 community buildings. Training courses on photovoltaic installation and operation for local technicians have resulted in ten Hondurans now running or working for photovoltaic businesses. Due to the success of this program, the Peace Corps in Honduras has incorporated photovoltaics into its Small Business Development sector as a standard mechanism for promoting economic development. Local contact: Phil Covell, Central American Program Coordinator, Enersol Associates, Apartado 216, Tegucigalpa, Honduras • phone 504-31-1613 • fax 504-32-5579. System supplier: Peace Corps (Honduras) volunteers in association with Enersol Associates and local technicians.

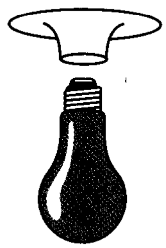
ENERGY CONVERSION DEVICES

These children are showing off one of the hundreds of photovoltaic-powered lanterns provided for homes beyond the reach of the power grid in India. These three- and five-watt lanterns are being made available to rural users through a market seeding distribution and service program co-sponsored by the U.S. Agency for International Development and the Rockefeller Foundation. To make the lanterns affordable, financial incentives are offered to private-sector organizations to purchase the photovoltaic lanterns in bulk and then lease them for the same amount that families formerly spent on kerosene for household lighting. Local service centers lease and maintain the lanterns and provide training to the users. The photovoltaic lanterns are powered by a tandem amorphous-silicon (thin-film) module and a nickel-metal hydride battery. The systems are a product of a joint US-Indian private venture and come entirely pre-packaged and assembled. Local contact: Vithal Rajan, DECCAN Development Society, A-6 Mura Appts, Basheerbagh, Hyderbad, India 500029 • phone 91-842-231260. System Supplier: Suryovonics Limited, 7-1-27/A Bequmpet, Hyderbad 500016, India • phone 91-842-290827 • fax 91-842-212032. Batteries supplied by Energy Conversion Devices (ECD).

This is just one of over 1000 lighting systems installed in scattered, isolated homes in the Navajo Nation in the western United States. About 30% of the Navajo residents have no electricity, and photovoltaics provides a better alternative to kerosene lamps and a less expensive alternative to the extension of power lines. For comparison, the photovoltaic systems cost about $1,500.00 each, while extending the power line costs an average of $19,000.00 per family. A typical system uses two 45-watt photovoltaic panels and two batteries to power three lights. Some panels are roof-mounted, while others are mounted on poles like this one. The systems are designed to accommodate future expansion. To improve the long-term success of the installations while boosting economic development in the area, the system supplier trained members of the Navajo Nation in the design, installation, maintenance and repair of photovoltaic systems. Local contact: Larry Ahasteen, Program Manager, Navajo Housing Services Dept., P.O. Box 2396, Window Rock, Arizona, USA • phone 602-871-6999. System supplier: Photocomm, Inc.

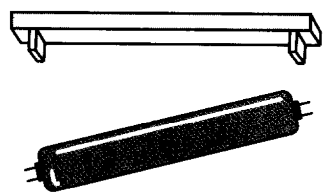
PHOTOCOMM INC.

LAMP A



INCANDESCENT LIGHT FIXTURE
(12 volt dc)
Power requirement: 25 watts
Illumination: 385 lumens
Total fixture cost ($US): 5.00
Replacement bulb cost ($US): 1.50
Average bulb life: 1,000 hours

LAMP B



FLUORESCENT LIGHT FIXTURE
(12 volt dc)
Power requirement: 8 watts
Illumination: 400 lumens
Total fixture cost ($US): 34.50
Replacement bulb cost ($US): 3.00
Average bulb life: 7,500 hours

THE IMPORTANCE OF USING EFFICIENT LIGHTING

The efficiency of a lamp (bulb) or fixture is a measure of how much power it requires to provide a given amount of light. Light fixtures and lamps vary greatly in efficiency. The majority of lamps on the market are designed for use with systems where the cost of the electricity is not a big concern, so efficiency is sacrificed in the interest of the cost of the lamp itself. In a photovoltaic system, however, the cost of the electricity (which is dependent on the cost of the photovoltaic modules) is a major factor, so it is very important to use the most efficient lamps available even if they cost more up front.

In our example, Lamp A, a 12 volt dc incandescent bulb, requires 25 watts of power to supply 385 lumens of light, while Lamp B, a 12 volt dc fluorescent bulb, requires only 8 watts to supply 400 lumens of light. Thus a photovoltaic system using incandescent bulbs would require more than three times as much photovoltaics as one using fluorescent bulbs to supply the same amount of light. A typical 48-watt photovoltaic module costs in the neighborhood of $350 (depending on local conditions), so even though the fluorescent fixture costs many times more than the incandescent fixture, it is generally much cheaper to use fluorescent lights instead of tripling the amount of photovoltaics to accommodate the power requirements of incandescent lights. Similarly, if you use the same number of modules for both photovoltaic systems, the total cost of the system using incandescent bulbs would be only slightly less than the total cost for the system using fluorescent bulbs, but would supply less than one-third as much light. Plus, fluorescent lights last more than seven times longer than typical incandescent bulbs (up to fifteen times longer for higher wattage bulbs). This not only lowers their cost over the life of the photovoltaic system, but also greatly reduces the need for replacements which may be difficult to locate in remote areas.

Unfortunately, the most efficient and cost-effective system configuration is often at odds with what is locally available. When a bulb eventually burns out it may be replaced with something much less efficient than the system is designed to accommodate. When this happens, the photovoltaic panel and battery cannot keep up with the increased demand for power, the system becomes much less effective, and the battery is often damaged. Similarly, it should be noted that in some low lighting situations, when lights are used for very short periods of time — say, a half-hour or less per night — it may be more cost-effective to use the cheaper incandescent fixture. In the interest of sustainability, it is sometimes more practical to sacrifice efficient system design in favor of using locally available components from the outset. In any case, a well-designed lighting system should include spare replacement bulbs if appropriate replacement parts are not locally available, and users must learn the importance of using lighting compatible with the photovoltaic system design.

HEALTH FACILITIES

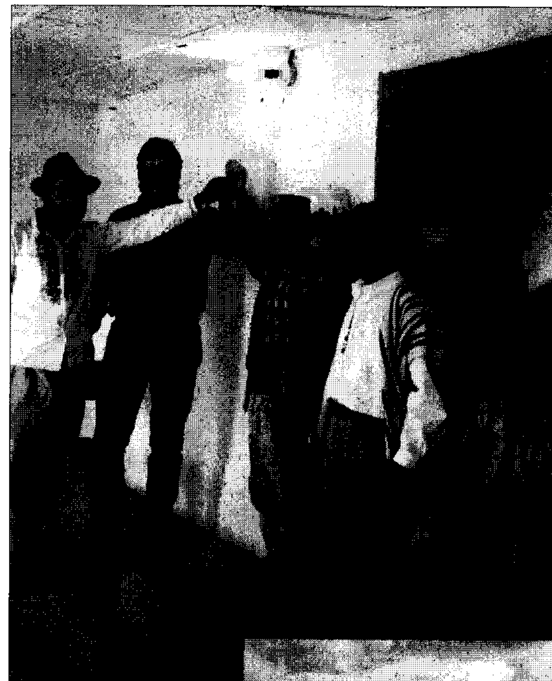
Photovoltaic systems play an important role in supplying life-saving vaccines and other medical services to people in remote regions of the world. Vaccines are extremely sensitive to temperature fluctuations and must be maintained between 32° and 46°F (0° and 8°C) to retain their potency. This becomes a formidable task in non-electrified regions, especially during transportation to remote health centers. International health organizations have incorporated photovoltaics into their vaccine delivery system (known as the "cold-chain") based on photovoltaics' ability to supply power to remote locations and because of the increased reliability and temperature stability of photovoltaic refrigeration systems when compared to their kerosene, gas and even grid-powered counterparts.

Our examples demonstrate just a few of the thousands of photovoltaic systems currently operating in rural and urban health facilities throughout the world. These systems maintain critically needed serums and power medical equipment, while supplying basic services that help attract and keep medical professionals who may be unaccustomed to working in rugged conditions.


VOLUNTEERS IN TECHNICAL ASSISTANCE

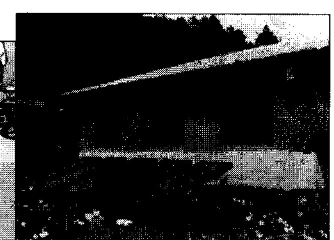
This photo demonstrates the versatility of photovoltaic systems. This local version of refrigerated transport used a photovoltaic-powered refrigeration system mounted on a camel to keep vaccines cool on the way to remote health clinics in the east African country of Djibouti. The local Ministry of Health sponsored this innovative link in the vaccine cold-chain in 1989; it worked well for about six months, until the camel driver demanded too much money for his services. Other camel-back photovoltaic refrigeration systems operated in Chad from 1987 to 1989. The 50-liter, World Health Organization-approved refrigerators are powered by three 48-watt Siemens Solar modules (formerly Arco Solar) and four 25 amp-hour batteries. UNICEF and other agencies in Africa, South America and Asia are currently operating over 200 stationary versions of this photovoltaic refrigeration system. Local contact: ISERST, P.O. Box 486, Djibouti, Republic of Djibouti • phone 253-35-27-95. System supplier: Jim Fanning, NAPS-Kenya, P.O. 19553, Nairobi, Kenya • phone 254-2-561-096 • fax 254-2-561-098.

This Paez Indian health center is located in the isolated, scenic village of Mosoco in the Colombian Andes. The five largest villages on this 200,000-acre reservation have electricity; the rest, like Mosoco, are unlikely ever to be connected to an electrical grid because the landscape is too rugged and the region too poor. Solar Energy International (SEI) collaborated with a local group, Fundación Antropológica de Tierradentro, to design and install a photovoltaic system capable of satisfying the center's estimated power needs of 2300 watt-hours per day. The resulting system consists of a 600-watt photovoltaic array, forty 150-amp-hour nickel-iron batteries, a charge controller, and an inverter. It supplies power for ac loads including five 11-watt lights, a television with video cassette recorder, and dental instruments, and dc loads consisting of battery chargers (for small rechargeable ni-cads) and a refrigerator. Throughout the installation process, SEI representatives trained local users and operators, taking into account their particular needs and abilities. In addition to this installation, the Paez Indians have asked SEI to demonstrate how they can use solar and renewable energy technologies to power schools, a radio station, and various small businesses. Local Contact: Jesús Gomez, Aprotec, Ave 9 A, No. 9-47, Cali, Colombia • phone 57-23-688026 • fax 57-23-470082. System Supplier (designer): Solar Energy International (SEI), P.O. Box 715, Carbondale, CO 81623, USA • phone 303-963-8855 • fax 303-963-8866.



SOLAR ENERGY INTERNATIONAL

This rural health clinic in Xecoxol was one of two clinics in Guatemala to receive a photovoltaic-powered vaccine refrigeration system in 1987, under a pilot project using U.S. Department of Energy funds in cooperation with the Organization of American States. Four other similar systems were installed in health centers the same year, two in Honduras and two in El Salvador. The system design meets the Pan American Health Organization specifications for vaccine refrigeration. Each system consists of six 40-watt panels, one 12-volt vaccine refrigerator/freezer (containing a dual compressor unit and a built-in charge controller), and a 369-amp-hour battery bank. The program also provided in-country training, to enable local people to work with and train future system operators, creating significant local business opportunities for installation and repair service of photovoltaic refrigeration systems. The other Guatemalan clinic, located in Las Lomas, reports no problems to date — the only necessary maintenance has been battery watering. A technician from the Honduran Ministry of Energy visits the clinic in Monte Redondo every three months; as of 1990, the resident nurse could not recall any system failures during four and a half years of operation. Local contact: Fernando Alvarez Paz, Guatemalan Ministry of Energy, Diagonal 17, 29-78 Zona 11, Guatemala C.A. 01011 • phone 502-2-763-182 • fax 502-2-762-044. System supplier: Diana Hasbun de Ayuso (Solarex Distributor), Sierya, S.A., Guatemala.



FLORIDA SOLAR ENERGY CENTER

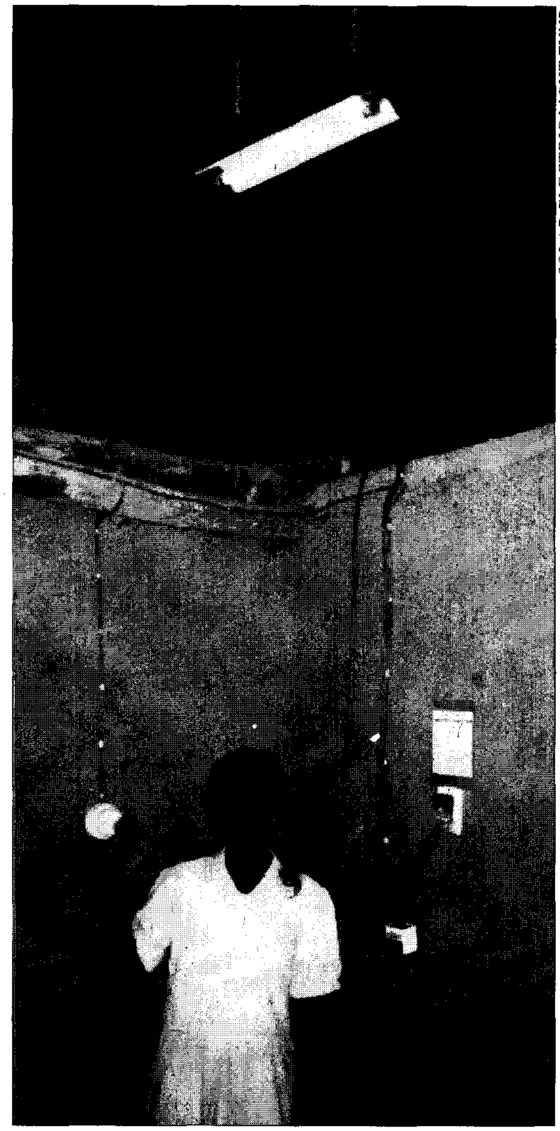
COMMUNITY PROJECTS

Photovoltaic systems can be designed to supply as little or as much power as you need. While small, individual systems provide services to remote, scattered dwellings, large systems (or networks of smaller ones) can power entire communities. For example, our story from Sri Lanka describes a town electrification project that was conceived and financed as a single village power scheme to install small systems on each of over fifty homes. Others towns, such as those described in our account from Mexico, use a more conventional centralized configuration: a single, large photovoltaic array is paired with other power sources in a hybrid system that distributes power through a mini-electrical grid to homes and businesses. Other common community power needs which photovoltaics can easily satisfy include street lighting, refrigeration, and communications for schools and community centers.

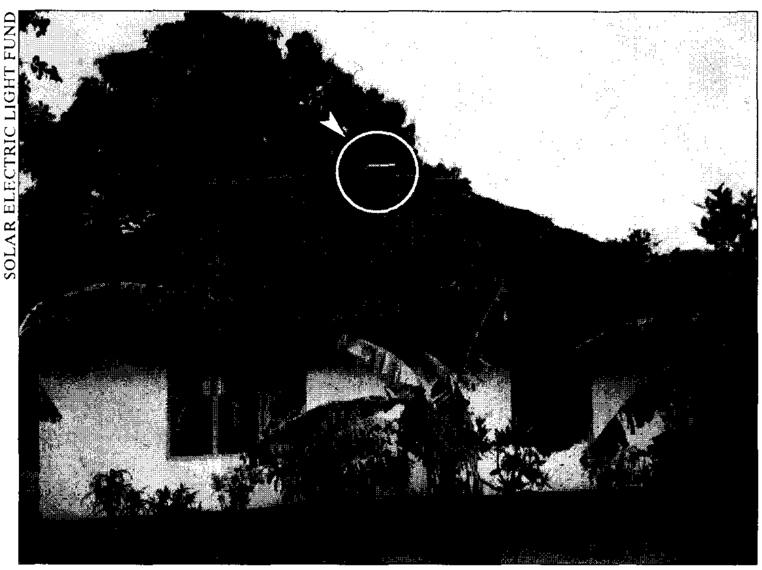
SUDAN NATIONAL POPULATION COMMITTEE

These women enjoy photovoltaic-powered lighting and refrigeration in the Women's Development Center in al-Ban Jadid, a rural community in western Sudan. People in this area suffer from malnutrition, partly due to the scarcity and high price of produce; a lack of electricity and communications exacerbates their poverty. In 1991, the local National Energy Committee collaborated with several non-government organizations and the Ministries of Health, Agriculture and Education to provide the Center with a 600-watt system to power lights, a refrigerator/freezer (for food and vaccine storage), a video player, and television. These services help educate villagers on family health, family planning and better agricultural practices. Now the women learn about solar energy along with tips on better crop cultivation and the effective management of local resources. The introduction of the photovoltaic system has enabled the Center to expand its services and to double the number of women trainees from 90 to 180 per course. Local contact: Samira Amin Ahmed, P.O. Box 3995, Khartoum, Sudan • phone 43641. System Supplier: NESTE Advanced Power Systems, P.O. Box 96, Rislokka, Norway 4 0516 • phone 47-2-723-012 • fax 47-2-722-435.

In the summer of 1992, the Solar Electric Light Fund (SELF) and its Sri Lankan associate SOLANKA helped the people of Morapatawa village establish the first "solar co-op" in this island nation. The Morapatawa Village Electrification Project provides basic lighting, communications, and battery charging to 50 homes and a Buddhist temple in this agricultural town of 250 people in northwestern Sri Lanka. A typical residential system consists of one roof-mounted, 20-watt photovoltaic module, a battery, and charge controller. Each system is designed to power a television, radio, and three 8-watt fluorescent lights. A SELF/SOLANKA trained technician lives in town and provides basic maintenance for the systems. For additional assistance, the villagers may call upon a fleet of motorcycle-equipped, traveling photovoltaic technicians employed by the local system supplier to assist with rural installations throughout the country. Most of the farming co-op members were able to afford the systems through a village-managed revolving credit scheme requiring monthly payments not exceeding their previous energy expenses for kerosene and dry-cell batteries. Local Contact: Priyantha Wijesooriya, Solanka Assoc. Inc., 8 Visaka Road, Colombo 4, Sri Lanka. See also Neville Williams, SELF, 1739 Connecticut Ave., Washington, D.C. 20009, USA • 202-234-7265 (fax & phone). System Supplier: Lalith Gunaratne, Joint Managing Director, Power and Sun, 338 T.B. Jayah Mawatha, Colombo 10, Sri Lanka • phone 94-1-686-307 • fax 94-1-575-599.



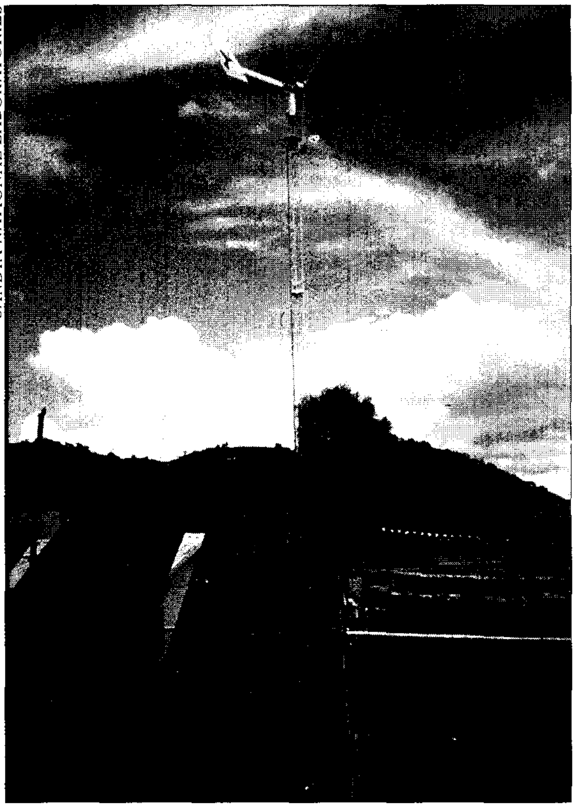
SOLAR ELECTRIC LIGHT FUND



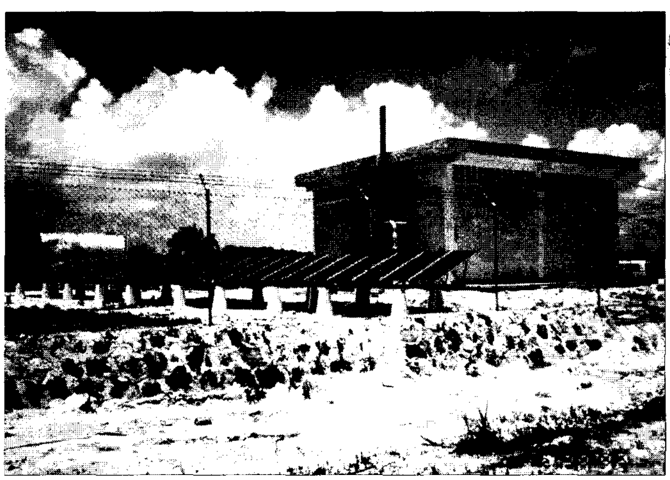
SOLAR ELECTRIC LIGHT FUND

Both of the hybrid systems pictured here are designed to make use of a trio of power sources, photovoltaics, wind, and diesel, to provide power for lighting, refrigeration, and communication (mainly television and radio) to two Mexican villages. These hybrid systems differ from the other photovoltaic installations presented here not only because they utilize multiple energy sources, but also because they produce electricity at a single, central location for distribution through power lines to multiple homes, businesses and community applications.

SANDIA NATIONAL LABORATORIES



This 45-kilowatt-hour-per-day installation in the village of Santa María Magdalena, about a two-hour drive north of Mexico City, delivers power to the town's stores, schools, homes, church and auditorium. The 4-kilowatt photovoltaic array is accompanied by a wind turbine rated at 4-kilowatts, an 18-kilowatt diesel generator, an inverter, and an 1100 amp-hour battery bank. The local utility company, Compañía de Luz y Fuerza del Centro (CLYF), Pronasol (the Mexican Rural Development Fund), and Westinghouse/Integrated Power Corporation funded the system, which was commissioned in spring of 1991. CLYF installed the distribution grid and assisted Integrated Power Corporation with on-site assembly. The villagers built the foundations for the wind turbine and the power-system shelter, and are assisting CLYF with maintenance; their participation is considered important to the overall success of this project. Local contact: Alfredo García, Compañía de Luz y Fuerza del Centro, S.A., Hidalgo, Mexico • phone 52-771-3104. System Supplier: Integrated Power Corporation.

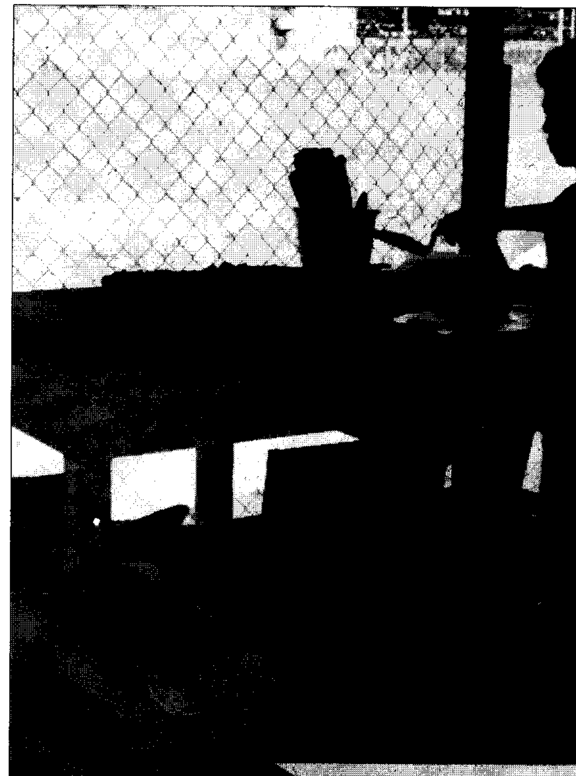


SANDIA NATIONAL LABORATORIES

This hybrid system serves Xcalac, a fishing village of around 350 people located along the Caribbean coast in the Mexican state of Quintana Roo. Extension of the existing power grid to this village was unlikely due to the long expanse of rugged, swampy terrain which separates the village from the nearest electric power line. Although the community already had a diesel generator, long-standing problems with its reliability, repair, maintenance, and fuel delivery led local and state governments to augment the existing 100-kilowatt diesel mini-grid system with six 10-kilowatt-rated wind turbines, an 11-kilowatt photovoltaic array, a 1738-amp-hour battery bank, and a 40-kilowatt inverter. The system was completed in August of 1992; the supplier visits the site every other month as part of a two-year maintenance contract. Soon the villagers hope to expand their fishing business with solar ice-making facilities for fish preservation. Local contact: Victor Sánchez, Jefe de Dpto. de Electrificación Rural, Comisión Federal de Electricidad, Chetumal, Quintana Roo, Mexico • phone 52-983-21470. System Supplier: Condumex (Siemens distributor), Nacional de Conductores Eléctricos, Fulton #2, Colonia Central Ind., C.P. 54030, Tlalnepantla, Estado de México, Mexico • phone 52-5-390-2434.

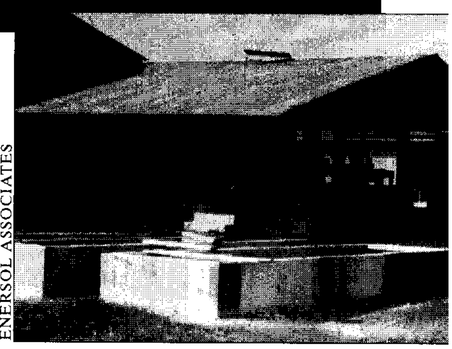
PRODUCTIVE USES

The use of photovoltaics can have a positive effect on local economies in several ways. Photovoltaic lighting systems can extend business hours and increase productivity of existing businesses. Photovoltaics can make possible endeavors requiring a source of power, such as freezing facilities for fisheries, electric fencing for livestock and range management, and industrial manufacturing applications, such as tile making. And, finally, businesses and jobs can be created to serve the photovoltaic industry itself, including system sales, installation, maintenance and repair. In Honduras, a Peace Corps initiative to promote small photovoltaic-powered enterprises has created a sufficiently large market to sustain several photovoltaic hardware and support businesses.



ENERSOL ASSOCIATES

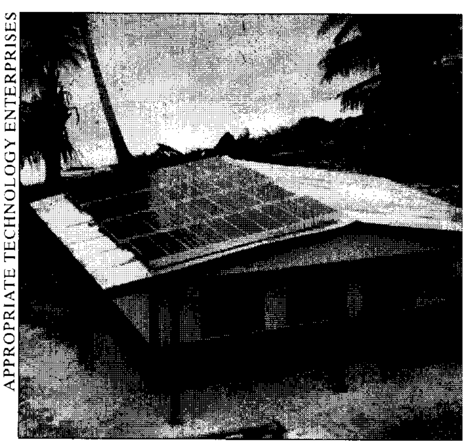
This roof tile factory uses power from a photovoltaic system to vibrate cement as a stage in the tile manufacturing process. The factory is part of a community development housing project in the port town of Tela, Honduras, and produces about 400 tiles per day. The project sponsor, Centro San Juan Bosco, is committed to expanding the economic development and living standards in this town of 34,000 and the surrounding area, and has endorsed photovoltaics as a means to this end. Although the factory is already hooked to an electrical grid, the vibrator is designed to work with an automotive battery. To demonstrate a productive use of the technology to local authorities and villagers, the Centro began charging the battery with photovoltaics in 1992. Power from the 40-watt module is routed through a locally-made manual control box to charge the battery and run the vibrator and a 15-watt light. The system was installed by local technicians and Peace Corps volunteers trained in a one-week course by Enersol Associates. Local Contact: Philip Covell, Central American Program Coordinator, Enersol Associates, Apartado 216, Tegucigalpa, Honduras • phone 504-31-1613 • fax 504-32-5579. System Supplier: Sistemas de Energía Solar Sorto de Santa Barbara, Honduras, and Siemens Solar Industries, Inc.



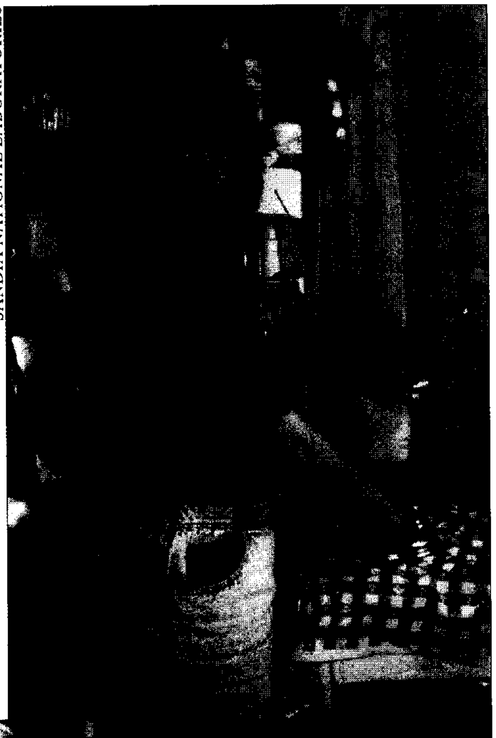
ENERSOL ASSOCIATES

This photovoltaic-powered freezer facility is situated on Wotho Island in the Republic of the Marshall Islands. Coconut and fish constitute the main cash crops for local islanders. While coconut meat can be dried and stored for export, the fishing industry has been stifled by lack of power for freezer facilities. So, the local government, with the financial help of the U.S. Department of Energy, contracted a local firm to install a photovoltaic-powered freezer unit in 1991. The photovoltaic system consisted of forty 53-watt modules mounted on the roof of the facility, a control system, a bank of twenty-four 1150 amp-hour deep-cycle lead-acid batteries and four Sunfrost 10-cubic-feet freezers. The system operated flawlessly for several months until Typhoon Gay ripped past Wotho Island in late 1992, taking the freezer structure's roof and photovoltaic modules with it. The Federal Emergency Management Administration (FEMA) is assessing the damage, but has not yet decided whether to replace the system. Although unfortunate, this incident indicates that special consideration must be given to the attachment and construction of roof-mounted arrays in hurricane-prone regions. With appropriate installation, photovoltaic systems often survive extremely severe weather conditions, including hurricanes. Local contact and system supplier: Steve Winter, Appropriate Technology Enterprises, P.O. Box 607, Chuuk, Federal States of Micronesia 96942.

APPROPRIATE TECHNOLOGY ENTERPRISES



These small businesses in the vicinity of Santa Barbara, Honduras, use photovoltaics to enhance their business activities. All three systems consist of one photovoltaic module (ranging in size from 20 to 48 watts), a locally manufactured car battery, and a manual control box (now also manufactured locally). These installations are the result of the Peace Corp's efforts in Honduras to incorporate photovoltaics into its Small Business Development sector activities as a tool for economic development (see also LIGHTING AND RESIDENTIAL POWER). Local contact: Peace Corps, Solar Energy Program, Apartado Postal 3158, Tegucigalpa, Honduras. System Supplier: Peace Corps (Honduras) volunteers in association with Enersol Associates and local technicians.

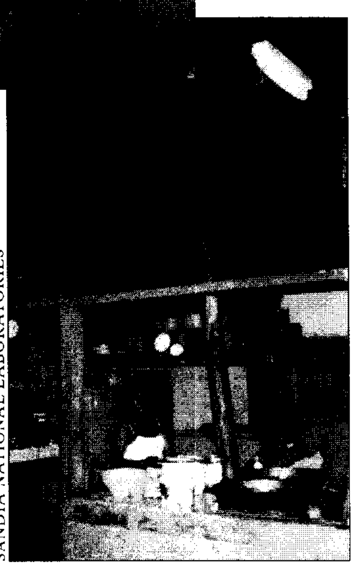


SANDIA NATIONAL LABORATORIES

Marina Reyes Herrera operates a small roadside *pulpería* (store) near the village of Atima. She was the first in her area to purchase photovoltaics, and uses the light provided by the system to extend her hours and attract customers traveling the road after dark. The system also provides power for a blender, which she uses to make and sell *licuados*, a drink made from the abundant tropical fruits which are grown in the area. A radio/tape player, also powered by the photovoltaic system, provides music and information to Marina and her customers.

SANDIA NATIONAL LABORATORIES

Gustavo Moreno also uses photovoltaics to provide power for lights, television, and a tape player in a *pulpería* near the town of San Luis. Prior to purchasing the photovoltaic system, he used a gas lantern for light, and dry cell batteries for the tape player, while a car battery, taken periodically to the nearest town for recharging, powered the TV.

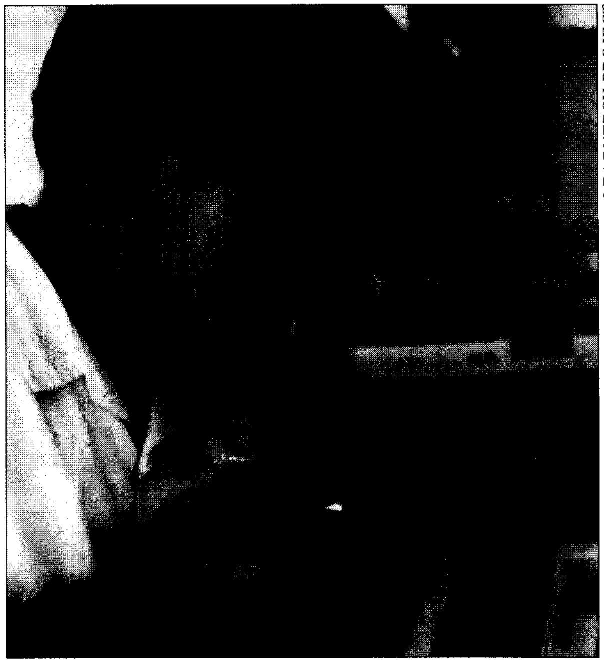


SANDIA NATIONAL LABORATORIES

Teovaldo Pacheco's fish restaurant is located on the shore of Lake Yojoa, and serves locally caught fish cooked over a wood fire. The photovoltaic system provides power for a radio (used all day) and three lights (each used about four hours a day), and Teovaldo is often able to charge an extra battery with excess solar power. Before obtaining the photovoltaic system, the family pick-up truck was used to recharge a car battery.

U.S.D.A. SOIL CONSERVATION SERVICE

These workers are installing an electric fencing system powered by a 10-watt photovoltaic panel on the tiny island of Saipan, 100 miles north of Guam, in the Northern Mariana Islands. The fence allows the farmers to continue to graze their cattle while protecting ecologically sensitive wetlands; by fencing off sections of their ranches and rotating the livestock through the different pastures, the grasslands have time to regenerate. Ultimately, these practices should result in more effective and productive use of the land with fewer negative environmental consequences. Twelve of these systems have been installed in a cooperative effort between local ranchers, farmers and the Soil Conservation Service. The program that provided for the installation of the systems did not require any financial contribution from the farmers; as a result their level of commitment to maintenance of the systems has been somewhat inconsistent. Overall, the systems (which also include a battery and fence charger) have worked well, although they have experienced some problems due to inadequate battery maintenance. Local Contact: Charles B. Frear, District Conservationist, USDA Soil Conservation Service, P.O. Box 5082, Saipan, M.P. 96950 • phone 670-233-3415 • fax 670-233-3857. System Supplier: K.M. Seed Company.

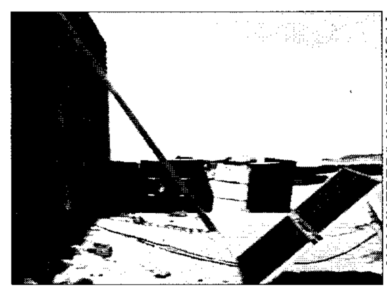


➤ LearnTech (The Learning Technologies for Basic Education Project) is a U.S. Agency for International Development-funded program that supports developing countries in the appropriate use of technologies to address critical needs in basic education. It makes creative use of available technologies such as interactive radio instruction and computer-aided learning. One approach is the use of electronic math games, such as Speak and Math™, for elementary school instruction. In rural areas with no access to electricity, these devices must be powered by dry-cell batteries, which are prohibitively expensive to replace. In 1992, Learntech purchased some rechargeable batteries and several four-watt photovoltaic-powered battery chargers to evaluate whether using photovoltaics would be a workable and cost-effective solution to the high cost of battery replacement in rural schools outside Belize City, Belize. The results indicate that, except for extended periods of rain, the photovoltaic chargers work very well and reduce the cost of powering the games sufficiently so that their use is financially feasible. LearnTech is also experimenting with photovoltaic-powered radios, and plans further work to address the problem caused by extended rainy periods. Local contacts: Vicky Pelayo, Belize Education Lab, 49 Front Street, Belize City, Belize • phone 501-245-491; also Steve Anzalone, Institute for International Research, 1815 N. Ft. Myer Drive, 6th Floor, Arlington, VA 22209, USA • phone 703-527-5546. System supplier: Photocomm Inc.

COMMUNICATIONS

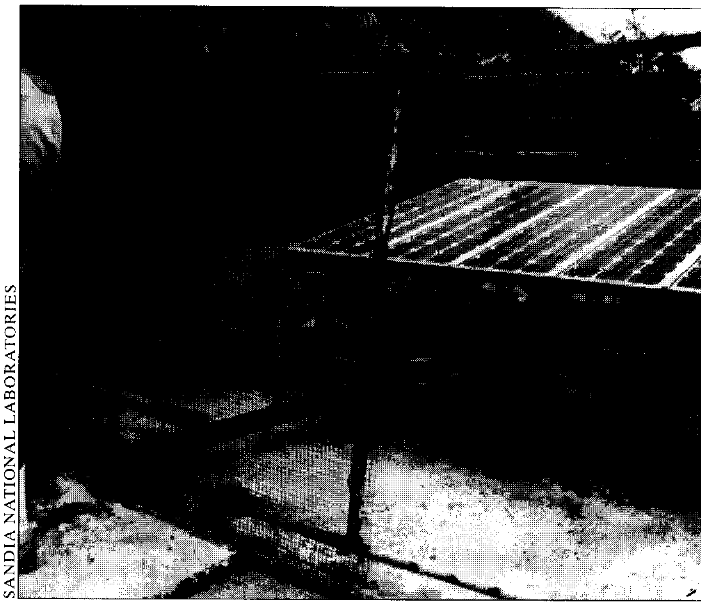
The ability to exchange information readily via electronic communication is commonly taken for granted in industrialized countries, but is often lacking in the developing world. Rapid and accurate information exchange is important to the success of health services, education, transportation, agriculture, energy and water management, government, disaster relief, industry and trade, social services, and economic development. Photovoltaics can provide reliable power for both large and small communications applications and has made electronic communications available for the first time to thousands of people living in remote regions of the developing world. For those relying on antiquated or overtaxed phone and electric lines, photovoltaic systems can fill this communications gap by enabling the use of radio and satellite technologies.

The examples of photovoltaic systems on these pages cover a broad range of system sizes and applications, ranging from using photovoltaics to recharge batteries for small radios and cassette players to powering microwave repeater stations linking the Bolivian and Brazilian national communications networks. Photovoltaics is also particularly well suited for systems which electronically link scattered islands, and for making televised education projects possible. Several photovoltaic system suppliers specialize in the design and installation of remote communication facilities.

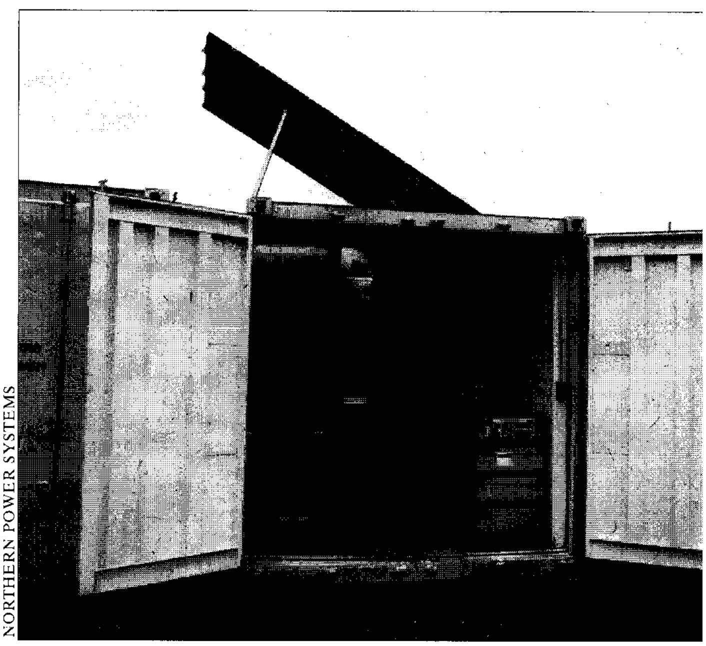


➤ This is one of six photovoltaic systems used to power a packet radio communications network which links United Nations Development Program offices scattered across 700 miles of rugged terrain in Sudan. Packet radio is a technology that combines two established technologies, personal computers and two-way radios, to provide reliable low-cost communication networks where no telephone lines exist. It is similar to communicating via computer modems and phone lines, except radios replace phone lines. Volunteers in Technical Assistance (VITA) offers packet radio technology as a mechanism for establishing information infrastructures within and between isolated areas and the rest of the world. Before the installation of these photovoltaic systems, no electricity was available at these sites to power the necessary equipment. The systems each consist of two 30-watt photovoltaic modules, 80 amp-hours of batteries, and a control system that powers the computer and radio equipment. Training in the operation and maintenance of the systems was provided to local technicians to ensure continued operation. Local contact: Ms. Malika Akrouf, Resident Representative, United Nations Development Program, Blvd. Marchal Joffre, Plateau du Serpent, Djibouti, Republic of Djibouti • phone 253-351361 • fax 253-350587. System supplier: Volunteers in Technical Assistance, 1600 Wilson Boulevard, Suite 500, Arlington, VA 22209, USA • phone 703-276-1800 • fax 703-243-1865.

The Mt. Tapotchao Communication Repeater Station and Weather Station is located on the island of Saipan in the Northern Marianas. It uses photovoltaics to provide power for the main communication and weather station in the islands. This installation illustrates the modularity of photovoltaic systems. In the early 1980s, the first of five photovoltaic systems was installed on the roof of the equipment building. As confidence in system performance grew along with the electricity needs of the facility, four additional systems were added in subsequent years. The five systems each have an average of 300 watts of photovoltaic modules and 600 amp-hours of battery storage. All five photovoltaic arrays are installed on the roof, which has a wire cage around it to protect it from vandalism and the rocks that occasionally fall from nearby cliffs. Local Contact: Frank Chong, Disaster Control Office, Emergency Operation Center, Capital Hill, Saipan, M.P. 96950 • phone 670-322-9229 • fax 670-322-3598 or -9237. System Supplier: Bill Michelin, Marianna Electronics, Gualao Rai, Saipan, M.P. 96950.

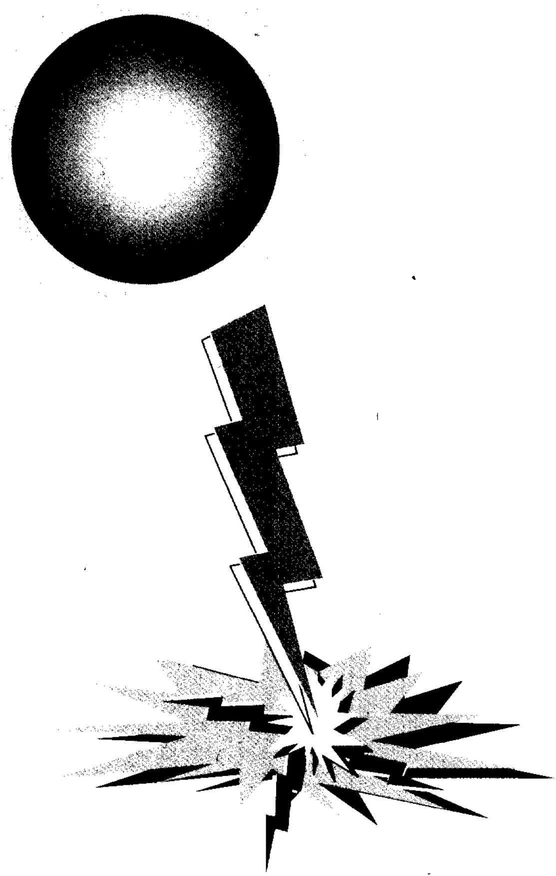

SANDIA NATIONAL LABORATORIES

This is one of fourteen photovoltaic/diesel hybrid power systems installed to power microwave communication stations in Bolivia. The systems, operated by AT&T and owned by the Bolivian national communications company, ENTEL, are situated at 30-40 mile intervals across 360 miles of the Bolivian high plains between Santa Cruz and Puerto Suárez. The systems extend telecommunications capability to previously unserved regions of the country and have peak photovoltaic power outputs ranging from 840 to 6240 watts. The photovoltaic arrays are coupled with diesel generators to charge each communication station's batteries and satisfy the electrical needs of digital microwave equipment, UHF radios, and support gear. A sophisticated controller orchestrates the automated operation of the photovoltaics and other system components. The solar panels provide 40 to 60% of the microwave systems' power requirements; the diesel generators automatically start to charge the batteries when necessary. A hybrid system was chosen for this application to minimize fuel consumption, generator "wear and tear", maintenance, and refueling needs. All systems were assembled in Vermont and shipped to Bolivia in modified shipping containers designed to provide shelter for the electronic components and a mounting structure for the photovoltaic array. To facilitate quarterly maintenance visits, ENTEL engineers received intensive training from the system supplier during assembly of the systems, as well as additional on-site training during installation. Local Contact: ENTEL, La Paz, Bolivia. System Supplier: Northern Power Systems, 1 North Wind Road, P.O. Box 659, Moretown, VT 05660, USA • phone 802-496-2955 • fax 802-496-2953.


NORTHERN POWER SYSTEMS

Why choose photovoltaics?

As our examples show, photovoltaic systems are successfully powering a myriad of development applications throughout the world. However, photovoltaics may not always be the best answer to every power need. It is important to consider both the advantages and limitations of photovoltaics before selecting it to power your particular application. Experience has shown that when users have unrealistic expectations of their photovoltaic system, they are likely to operate it improperly or simply quit using it altogether. The following discussion summarizes the basic characteristics of photovoltaics to help you know when it is the right choice.



SUNSHINE IS FREE AND ABUNDANT

ADVANTAGES OF PHOTOVOLTAIC SYSTEMS

- COST-EFFECTIVE — In many instances, life-cycle costs for photovoltaic systems are lower than for non-renewable alternatives, including power grid extensions.
- RELIABILITY — Photovoltaics is often the preferred power option for critical applications that require a consistent, predictable energy supply, such as for health care, military communications and emergency power applications. The technology is well established, with tens of thousands of installations in both developing and industrialized countries.
- LOW MAINTENANCE — Most photovoltaic systems operate with little servicing and no refueling, making them popular power sources for extremely inhospitable or isolated locations, such as mountain tops or outlying islands.
- ENVIRONMENTALLY BENIGN — Photovoltaics produces no gaseous emissions during operation and offers an environmentally benign alternative to fossil and nuclear sources of energy. Plus, the technology operates silently and may offer a visually pleasing alternative to miles of power conduits strung across the landscape.
- FREE, ABUNDANT FUEL — Of course, sunshine is free, widely available, and virtually inexhaustible — photovoltaic systems have no monthly fuel bills.
- LOCALLY GENERATED POWER — Photovoltaics make use of a local resource — sunlight. This provides greater energy security and control of access to energy. It also reduces the dangers of transporting acid-filled batteries to recharging stations.
- FLEXIBLE SIZE — Photovoltaics can produce enough power for just about any application you can envision. Existing systems range in size from pocket calculators to multi-megawatt power plants. Their modular construction facilitates easy expansion of systems as finances allow and needs demand.
- TRANSPORTABILITY — As photovoltaic systems are modular in nature, they can be transported in pieces. In addition to simplifying the logistics of transport to remote areas, this feature allows for relatively easy relocation and protection from severe weather conditions.

SANDIA NATIONAL LABORATORIES

Discarded batteries stacked along a roadside outside Tegucigalpa, Honduras.

LIMITATIONS OF PHOTOVOLTAIC SYSTEMS

- SUN DEPENDENT — An engine generator won't run without fuel, and photovoltaic systems won't run without sunlight. Sunlight is a diffuse fuel source, therefore photovoltaic systems are energy limited, and probably are not the best choice for applications with high power requirements, such as air conditioning or resistance heating — especially if they are needed at night. Applications which use power at night require batteries, increasing the system cost and complexity. Clouds blocking the sun or shadows cast by vegetation and structures will diminish the system's output.

- HIGH INITIAL COST — Although many rural dwellers already pay dearly for energy, some sort of financing is needed to spread the high initial cost of photovoltaic systems out over the life of the system and make them accessible to cash-poor rural dwellers. The import and custom fees levied by many countries may exacerbate these costs.

- SYSTEM MAINTENANCE — Although photovoltaics requires relatively little upkeep, batteries need regular maintenance and eventual replacement; some training is useful to safely maintain and operate a complete photovoltaic system.

- DISPOSAL — Ultimately, photovoltaic systems will become someone's trash — although most commercial photovoltaic materials pose no toxic threat to humans or our environment, most batteries do contain hazardous materials and a means for careful recycling or disposal should be included in the long-term project design and funding scenario.

- POWER TYPE — Photovoltaic modules produce direct current (dc) electricity only; an inverter must be added to the system to run alternating current (ac) devices. Although this adds to the system cost and complexity, it also enables the use of more readily available, and often cheaper ac appliances.

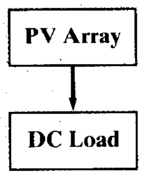
- VULNERABILITY — The same modular and portable characteristics that allow easy expansion of photovoltaic systems leave them vulnerable to theft and vandalism. Some systems are constructed so that the photovoltaic panels can be brought inside at night, while others are situated so that they are barely visible to would-be thieves.

Basic photovoltaic system design and procurement

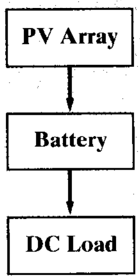
Once you have determined that photovoltaics is a suitable power source for your application, you can proceed to the next stage: selecting or designing a system. The photovoltaic industry has simplified the buyer's selection process by supplying more and more pre-designed, packaged photovoltaic systems. However, many photovoltaic systems must be customized to suit a particular application or location. The design process requires the consideration of several factors, including the characteristics of the installation site, how much power you need and when, the type of power required (ac or dc), the criticality of your application, and whether the system will be easily accessible or will be installed in a remote location. A reputable supplier will be able to help you decide what type of system is most appropriate for your application. A concise directory of US photovoltaic systems suppliers is provided at the end of this booklet, along with a list of photovoltaic directories.

The vast majority of existing photovoltaic installations are *stand-alone* (as opposed to *grid-connected*), which work either independently or as hybrid systems. Both hybrid and autonomous stand-alone systems may or may not include batteries. Systems with batteries may require charge controllers and low-voltage disconnects to protect the batteries from too much charging or discharging. Not all loads can use the dc power produced by photovoltaic systems; inverters are added to these systems to convert dc to ac electricity. Finally, switches and control boxes, mounting hardware, and fuses are also included in the balance of systems (BOS), and sun trackers are sometimes used to increase the output of the photovoltaic array. *Grid-connected* systems use the utility for energy storage, feeding power to the grid during the day and drawing power from it at night. They are less common than stand-alone systems, largely because they are not yet cost competitive with the existing centralized power generation networks.

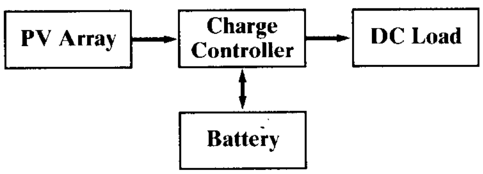
PHOTOVOLTAIC SYSTEM TYPES



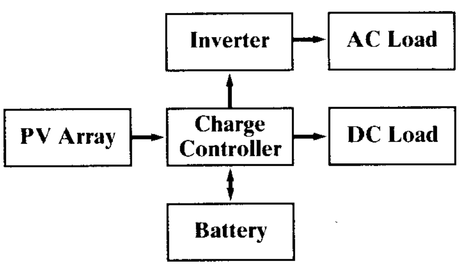
Direct-Coupled



DC load with battery.



DC load with battery and charge controller.



DC & AC loads with battery, charge controller & inverter.

STAND-ALONE PHOTOVOLTAIC SYSTEMS

Stand-alone photovoltaic systems produce power independently of other energy sources. This diagram shows four system configurations of increasing complexity. All of these systems can operate without batteries, such as a direct-coupled photovoltaic water pumping system; however, most applications, such as lighting, require batteries to store energy for use at night or on cloudy days. A charge controller is often added for battery protection, and an inverter is required to run ac loads. These stand-alone systems comprise the majority of photovoltaic installations in remote regions of the world because they are often the best, most cost-effective choice for applications far from the utility grid which require reliable power and low maintenance.

MAJOR STEPS IN PHOTOVOLTAIC SYSTEM DESIGN

The complexity of photovoltaic systems varies with their particular application but the nuts & bolts of system design are fairly straightforward:

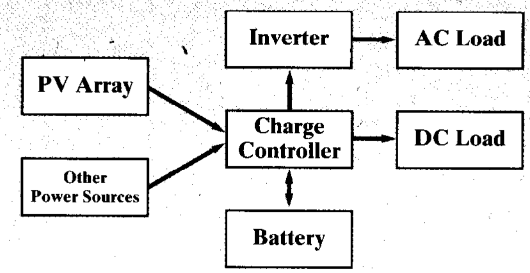
FIRST, FAMILIARIZE YOURSELF WITH THE SOLAR RESOURCE AND SELECT A SITE. Gather weather data to estimate the maximum and minimum daily sunlight hours available during the different seasons: the *International Solar Irradiation Database* is one source for insolation levels for various regions (University of Lowell Photovoltaic Program, Lowell, MA, USA, July 1991); local inhabitants and weather bureaus may provide information on micro-climatic conditions, such as cloud cover, fog, dust, wind, etc., which will affect the system's performance. Assess potential shading problems from terrain, foliage and buildings.

SECOND, ESTIMATE YOUR ENERGY NEEDS. How much energy do you expect to use over the course of a day, and what will the peak demand be at any given moment? Will power be needed both during the day and night? What kind of appliances and equipment will be used, and for how long each day? Will the usage be constant, or will it fluctuate with seasons, school terms, holidays...? Try to be realistic — an undersized system will frustrate its users, while an oversized one will waste money. It is important to design for the worst case by comparing seasonal variations in the solar resource with seasonal variations in usage.

You also need to assess the type of power needed. Will the load require direct or alternating current? Although dc appliances and machinery tend to be more efficient, you may need an inverter to condition the current for use by a computer or another electronic device that runs on ac power. Plus, ac appliances tend to be cheaper and more readily available than some dc devices. An inverter will reduce system efficiency somewhat and increase costs, but it may be necessary to satisfy user needs now or in the future.

Efficiency and conservation will generally save you money in the long run. Whether your power loads consist of ac or dc powered appliances, try to use the most energy efficient devices available, and only power what you really need. For example, for most lighting applications you should consider dc fluorescent lamps instead of incandescent because they produce more light per watt than do incandescent bulbs. Their initial higher cost is more than compensated by their increased efficiency and longevity: an 8-watt fluorescent can produce more light than a 25-watt incandescent bulb, and the fluorescent lasts over seven times the life of the incandescent bulb — up to fifteen times as long for high-wattage bulbs (see LIGHTING AND RESIDENTIAL POWER for more information).

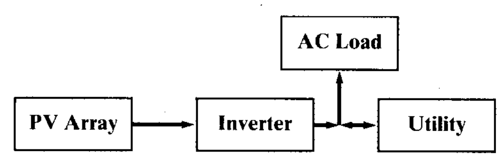
PHOTOVOLTAIC SYSTEM TYPES *(cont.)*



Hybrid system with ac & dc loads, battery, charge controller, & inverter.

STAND-ALONE HYBRID SYSTEM

In a stand-alone hybrid system the photovoltaic array is coupled with one or more additional power sources that are not sun-dependent, such as a wind and/or diesel generator. Hybrid systems may be the most cost-effective choice to provide power for large scale applications, especially when another power source is already available and/or greater system availability is desired. A photovoltaic system supplemented by another power source may require fewer photovoltaic panels and batteries (for power storage), thus reducing the overall power system costs. If you need a large amount of energy (say, more than several kilowatt-hours of power per day), year-round, and particularly if you already have a generator or if you live in an area where sunlight availability is poor for long periods, a hybrid system may be a good choice.



Grid-connected or utility-intertied system, ac loads only.

GRID-CONNECTED SYSTEM

In a grid-connected system the photovoltaic system acts as a miniature power plant, feeding excess power directly to the utility during the day, and drawing from the grid at night and in periods of low sunshine. In developing areas a grid-connected system may make the most sense as a backup for an irregular utility power supply. For example, a grid-connected system may be the choice of health centers in urban areas that are dependent on a steady supply of electrical power to refrigerate fragile vaccines, or to power lights during surgical procedures.

THIRD, CALCULATE THE BATTERY SIZE, IF ENERGY STORAGE IS NEEDED. Photovoltaic battery systems are usually sized to provide several days of energy storage to meet the load during periods of low sunlight. The days of storage (or "autonomy") required depend on the criticality of the application. For example, the consequences of being unable to operate a light are usually not as severe as losing power to a vaccine refrigerator. Less critical applications may use three to four days of storage, while more critical applications (such as those that would impact public safety or health) may require more. In extremely critical applications, it may be most economical to include a hybrid or backup power source, instead of providing funds for extra battery storage.

FOURTH, CALCULATE THE NUMBER OF PHOTOVOLTAIC PANELS YOU WILL NEED. The size of the array is determined by the daily energy requirement divided by the available sun-hours per day. Generally, for a load that remains constant all year, the photovoltaic array is sized to meet the load during the lowest annual sunlight conditions, such as the winter rainy season. In addition, power losses are inherent in some components of photovoltaic systems, so it is important to consider these when calculating the exact number of photovoltaic modules required.

Other Design Considerations

- **Assess the local support infrastructure** — Who can install, maintain, and repair the system or its loads? Are satisfactory tools and replacement parts available, and at a reasonable price?
- **Strive for simplicity** — System complexity generally lowers reliability and increases the need for technical support.
- **Require documentation** — Make sure the installer provides system operation and maintenance information in a form and language easily understood by the system operators. It may be useful to keep some kind of record, preferably written, of changes to the system in addition to the regular installation, operation and maintenance information.
- **Understand system availability** — Technically, photovoltaic systems with energy storage can provide power all times of the day or year. However, the additional cost of adding extra modules or batteries to make the system available 100% of the time must be weighed against the inconvenience of achieving slightly lower availability at a significantly lower cost.

- **Install the system carefully** — Use the right tools and technique. Make each connection as if it had to last 30 years — it does. The system reliability is no better than its weakest connection.
- **Plan periodic maintenance** — Photovoltaic systems have an enviable record for unattended operation, but no system works forever without some care. Batteries, in particular, require periodic attention and eventual replacement.

For a more detailed design process, please refer to the photovoltaic guides and software programs listed under ADDITIONAL SOURCES OF INFORMATION.

FINDING EQUIPMENT

After determining your basic system requirements, you are ready to find a supplier and/or installer. If possible, seek out experienced and reputable system suppliers and installers who use quality equipment and provide warranties and local support services. The way you approach this will depend on your project, location and institutional set-up. You may wish to advertise your system needs as a competitive bid opportunity through a mass mailing to the industry, and/or postings in pertinent industry journals, periodicals, work places, computerized bulletin boards, etc.. When preparing a bid request clearly state what you want the system to do; choose the supplier with the most suitable system for the least cost *and* the most appropriate qualifications and experience.

The international photovoltaic supply network is extensive and growing. In addition to photovoltaic system suppliers, you can find more and more small, pre-designed systems in hardware stores, lighting outlets and general stores in both industrialized and rural developing areas. A list of major U.S. photovoltaic system suppliers is presented at the end of this booklet. In addition, the photovoltaic industry directories presented in ADDITIONAL SOURCES OF INFORMATION provide addresses for international photovoltaic system component suppliers; also, the various photovoltaic associations listed there will be able to help you find and assess a reputable contractor.

Locating a reliable photovoltaic system supplier is one thing — paying for goods and services may be a more formidable task. Our next section offers some innovative approaches to overcome the financial, social and institutional barriers that may impede the purchase and installation of your system, especially in a developing region.

Financing and the importance of infrastructure

"...[S]olar electricity, like other indigenous sources of energy, may save a nation hard currency, while providing the additional benefits of rural development, employment generation, increased self-reliance (both on an individual and national level), and reduces vulnerability to crises in the world oil markets."
— BRUNDTLAND COMMISSION, 1987

The success of a photovoltaic installation relies not only on a sound system design and installation, but also on the support and participation of the people it serves. To ensure the long-term success of a photovoltaic installation it is important that the system promote the social and economic well-being of its users by providing desired services and stimulating the local economy. An enthusiastic and knowledgeable photovoltaic clientele is likely to create a self-sustaining market for technical services and related enterprises. A small amount of training not only encourages proper operation and maintenance of systems but can also lead to the growth of new businesses specializing in technical and hardware support, or even electrical appliances, as more and more people are "electrified". On the other hand, a photovoltaic system designed without the users' input and training is less likely to satisfy their needs.

PROMOTING A SUSTAINABLE PHOTOVOLTAIC INFRASTRUCTURE

- **CREATE AN INTEREST IN THE TECHNOLOGY.** For people who have never seen photovoltaic systems in action, a simple but effective demonstration project may capture their interest, especially if it supplies a service they want, need, or which promotes the local economy. The use of photovoltaics in the cement tile factory in Honduras is one example of a successful photovoltaic demonstration project (see PRODUCTIVE USES).

- **EDUCATE POTENTIAL USERS.** Let them know what a photovoltaic system can do for them, and what it cannot. If a system is oversold, chances are its owners will be disappointed with its performance and may harm it or themselves through inappropriate use.

- **ESTABLISH LOCAL SYSTEM PARTS SUPPLY, INSTALLATION AND REPAIR SERVICES.** Training may also foster the growth of new technical support enterprises that bolster both the photovoltaic system market and the local economy in general. In many cases, such as in the Dominican Republic and Honduras, small vending, servicing, and manufacturing facilities have sprung up in response to the growing photovoltaic market.

- **INVOLVE THE USERS FINANCIALLY.** Experience indicates that the most successful photovoltaic installations require at least a partial financial commitment from the users. Having an interest in the success of an investment from a financial as well as operational standpoint tends to pique interest in its long-term viability. Our next discussion will show some of the innovative financing schemes currently enabling cash-poor rural dwellers to purchase services provided by photovoltaics.

FUNDING A PHOTOVOLTAIC PROJECT

Photovoltaics is an established technology with many appropriate and cost-effective applications. As costs decline, it will become increasingly competitive with other more conventional power sources. Yet, even with low life-cycle costs, the high initial costs associated with photovoltaics can keep it out of reach of many who could benefit from it most, especially in cash-poor areas of the world.

So, how can an individual or small organization afford to purchase a photovoltaic system? One answer is a loan which divides the initial sum into affordable monthly payments. For organizations interested in providing financing, a grant may furnish seed money to establish a revolving loan fund.

Sources for Grants and Loans

As energy demands grow and national budgets tighten, government energy ministries are looking more often to the private sector for energy investments. However, international development banks and aid organizations remain important sources for loans and grants for energy-related programs.

Generally, multilateral development banks provide loans, while the regional development banks provide grants (see MAJOR DEVELOPMENT FUNDING SOURCES FOR RENEWABLE ENERGY PROJECTS); other government sponsored and private philanthropic institutions may provide grants, with various levels of restrictions. Bilateral assistance agencies include the development and export assistance agencies of industrialized nations. They usually provide grant money with the stipulation that all related equipment be purchased from manufacturers within the country; these restrictions may also require that the recipient organization be located within the agencies' home country as well.

SANDIA NATIONAL LABORATORIES

PHOTOVOLTAIC TRAINING

Local technicians, business people, and representatives of local non-government organizations receive photovoltaic training as part of a Peace Corps/Enersol small business initiative in Honduras. This class is part of a Peace Corps effort to promote small enterprises while helping to bring solar power to over three million Hondurans who live beyond the electrical grid. The Peace Corps has found that education and an established technical support network are essential to the long-term success of the solar program. Peace Corps volunteers collaborate with Enersol Associates to offer five-day workshops, which cover photovoltaic technology and system design, along with suggestions for starting new businesses. This course includes two days of system installations, which give students real-life experience with photovoltaics. After completing the installations, the newly-trained photovoltaic technicians teach the owners about basic system operation, maintenance, and battery safety.

The program has been effective. Since late 1991, over sixty homes, churches, health centers and small businesses in Honduras have been outfitted with photovoltaic systems to power lighting, communications and other services. At the same time, a local support network has grown up to sustain this new market, including solar technicians, suppliers, and manufacturers of systems components, such as control boxes and lighting.

But this is not a give-away program — all of these systems were purchased and installed as part of regular business transactions, a practice Enersol and the Peace Corps find prompts the owners to take better care of their systems. To help get a typical $700.00 system into the hands of typical Hondurans, Enersol and other local non-government organizations have helped establish credit schemes. Because the modules, at least, can be purchased on short-term credit, a few tools and a little working capital are enough for a trained technician to get into the solar business. For more information contact the Peace Corps - Solar Energy Program, Apartado Postal 3158, Tegucigalpa, Honduras • fax 504-325399.

BUILDING A PHOTOVOLTAIC INFRASTRUCTURE

These workers are revitalizing a photovoltaic-powered water pumping system in the village of Corozal. In the mid-1980s, Volunteers in Technical Assistance (VITA) joined with the USAID-funded development organization, APRODIB (Asociación Pro-Desarrollo Islas de la Bahía), to provide photovoltaic-powered water pumping systems to Corazol and four other villages on the island of Roatán, Honduras. All the systems experienced initial pump problems, and, by April 1992, only two pumps were operating, and at a reduced capacity. The photovoltaic portion of the systems operated well throughout this period, experiencing only minor problems with wiring and shading (the "live" fence posts surrounding the system sprouted and grew into trees.)

Although the villagers were involved in the initial installations (monetary contributions, labor and administration), social and infrastructure problems led to dissatisfaction with the systems, and this contributed to their neglect and deterioration. Although each village has a Water Board charged with fee collection and maintenance of the distribution system, both have been sporadic and inconsistent. In addition, the technical knowledge and associated infrastructure necessary to repair and replace the photovoltaic pumping systems did not exist on the island, leaving the villagers without water due to simple (but technically foreign) wiring problems; in some cases the malfunctioning systems were abandoned altogether.

In November 1992, VITA again joined with APRODIB and the villagers, along with Sandia National Laboratories' Design Assistance Center, to rehabilitate these systems and to address the social and technical issues remaining as obstacles to their success. A team of VITA, Sandia and volunteer US industry representatives replaced three inoperative pumps, rewired four arrays, and serviced four tracker systems. As this work progressed, a VITA representative and the local Peace Corps volunteer met with delegates from each community to identify and reduce institutional reasons for systems failures. The villagers assisted with the system rehabilitation, and selected individuals received hands-on operation and maintenance instruction. Perhaps most importantly, during the preceding year the Peace Corps sponsored a program which taught the islanders about photovoltaic technology and its applications. This effort resulted in the formation of a local photovoltaic business, whose technicians participated in the water system rehabilitations, and which will provide continuing local photovoltaic maintenance for the pumping systems. APRODIB engineers also received photovoltaic training and will help bolster the village and island photovoltaic infrastructure during the first year of revitalized system operation. Local contact: Nelson Perdomo, APRODIB, French Harbour, Roatan, Honduras • phone 504-45-1104 • fax 504-45-1363. System Supplier (revitalization): Solar Engineering.


SOLAR ENGINEERING

IMPEDIMENTS TO FUNDING

Despite the benefits of photovoltaics, the international financial community has been relatively hesitant to fund non-conventional, small-scale energy projects. Large lending institutions tend to prefer investing in massive power projects using well-known, familiar technologies, like hydroelectric dams or diesel generators.

There are several explanations for this hesitancy. First, international financing institutions have a history of being unaware of and fearing new technologies that are not often included in standard country development plans; however, many governments are combating this bias by financing research & development and demonstration projects designed to educate the public about photovoltaics and other renewable energies. Second, photovoltaics (and other renewable energy technologies) require a regulatory and institutional infrastructure that often does not exist in developing countries. Third, numerous small photovoltaic projects are more costly and difficult to administer than fewer, larger centralized projects, even though smaller projects are often more technically viable. And fourth, photovoltaics (along with other renewable energies) is a relatively young industry largely comprised of small businesses with limited experience in project financing on an international scale.

A number of organizations and individuals are actively working to break down these barriers. In an attempt to improve their ability to fund small, but effective, development organizations and projects, the World Bank has established special funds, such as the Rome-based International Fund for Agricultural Development (IFAD), earmarked for activities sponsored by non-government organizations (NGOs). Although multilateral development banks deal only with national governments, they now have affiliate organizations that provide assistance directly to non-government enterprises. In addition, the World Bank has established the FINESSE program which bundles small renewable energy projects into one administrative unit (see INSTITUTIONALIZING SMALL-SCALE ENERGY FUNDING: FINESSE).

A detailed review of the functions and structures of international banking institutions is provided by the International Institute for Energy Conservation, *The Least Cost Energy Path for Developing Countries*. In addition, the USAID *Directory of U.S. Renewable Energy Technology Vendors* recommends strategies to use when approaching large lending institutions. Also, the Solar Energy Industry Association publishes the booklet *Financing Renewable Technologies*. See the SELECTED BIBLIOGRAPHY and ADDITIONAL SOURCES OF INFORMATION for information on acquiring these documents.

Alternative Funding Scenarios

Rather than wait for institutional change, a few creative entrepreneurs have discovered ways to circumvent the impediments to funding small photovoltaic projects. One answer, like the World Bank's FINESSE program, is to package several projects together to create a single one large enough to qualify for loans from the major international financial institutions. This umbrella approach reduces bureaucratic paperwork for the large funding institutions and can be much more attractive to them than multiple individual projects. Several organizations, programs and consulting firms now specialize in facilitating these collective ventures, including IFREE and FINESSE.

Some non-government organizations have developed their own financing capability by raising a relatively small amount of seed money (e.g., $2,000.00 to $20,000.00) to establish a revolving loan fund: credit is extended to local buyers of small photovoltaic systems (such as residential lighting systems) at prevailing interest rates; monthly payments are determined at or below their previous energy-related expenditures. This money is returned to the fund to allow others to purchase more small systems. Examples of this type of funding mechanism are presented in our examples of ADESOL/Enersol in the Dominican Republic and Morapatawa village electrification project in Sri Lanka (see COMMUNITY PROJECTS). In addition, as the photovoltaic industry matures and the infrastructure expands, more companies will be able to offer financing directly to their customers, much like the automobile industry.

ENERSOL ASSOCIATES

A REVOLVING FUNDS: FINANCING THAT WORKS

ADESOL (Asociación de Desarrollo de Energía Solar) is a rural development association which provides consumer credit to rural clients for small residential photovoltaic systems in the Dominican Republic. ADESOL's revolving credit funds typically require consumers to pay a minimum of 25% down on a system and provide a loan for the balance to be paid back over 24-26 months at prevailing interest rates. A typical 30- to 50-watt photovoltaic system costs between $500.00 to $700.00 (US) installed and requires the replacement of a $45.00 battery about every 18 months. This displaces $100.00 to $150.00 of annual expenses previously incurred for the consumption of kerosene for lighting, dry-cell batteries for radios and cassettes, and the use of motor vehicle batteries to operate televisions. This money is returned to the fund to allow others to purchase systems.

ADESOL was created as part of the ongoing efforts by Enersol Associates to build the institutional support needed for solar-based rural electrification. The project began during 1984 in Bella Vista, a rural town where Enersol demonstrated photovoltaic technology and established a working model for developing a photovoltaic system hardware supply enterprise (Industria Eléctrica Bella Vista), along with ADESOL for providing credit. Enersol uses the model to educate others about rural photovoltaic electrification and to establish similar activities throughout the country. As a result, technicians trained and assisted by Enersol have installed over 2000 systems, and rural associations have financed hundreds of consumers. Enersol, with support from Sandia National Laboratories, operates a similar program in Honduras, and has provided technical assistance and advice to initiate efforts in Sri Lanka, Bolivia, Zimbabwe, Guatemala, Yemen, Bangladesh, and elsewhere. For more information on ADESOL or Enersol contact Enersol Associates, Inc., 1 Summer Street, Somerville, MA 02143, USA • phone 617-628-3550 • fax 617-623-5845.

FINANCING RURAL DEVELOPMENT IN MEXICO: PRONASOL

The Mexican government is pursuing an ambitious national program, PRONASOL (Programa Nacional de Solidaridad), to improve the social and economic conditions of millions of the country's rural poor. As rural electrification is a major component of the program, PRONASOL works closely with the national utility, CEF (Comisión Federal de Electricidad), to identify areas where grid extension is not anticipated in the near future. Photovoltaics, along with other renewable energies, is providing alternative power to bring basic services to these remote areas. To date, 15,000-20,000 photovoltaic systems have been installed in residences and businesses throughout the country.

Creative financing strategies help the country's cash-poor rural customers purchase these power systems. Photovoltaic rural-electrification projects under PRONASOL fall into two categories for financing purposes: general rural electrification (including residential and community applications), and productive uses. Government grants cover costs for rural electrification for non-revenue-generating applications. In most cases, federal contributions amount to fifty percent of the total project cost, while the state government provides thirty percent. The local government and community users share the cost of the remaining twenty percent. User contributions may vary according to their ability to pay, and loans can be repaid in-kind by providing services or supplies if cash is in short supply. Photovoltaic systems installed for productive applications must demonstrate economic viability to obtain preferential loans (rather than grants) from Mexican development banks. Loans are generally paid back to the bank from business profits. For both project types, the user is responsible for all future costs, so many communities have established revolving funds to pay for anticipated system expansions, repair and maintenance. For more information, contact the Mexican National Agency for Social Development, SEDESOL.

INSTITUTIONALIZING SMALL-SCALE ENERGY FUNDING: FINESSE

FINESSE, which stands for Financing Renewable Energy for Small-Scale Energy Users, was created by the World Bank's Energy Sector Management Assistance Program (ESMAP) in 1989, to provide workable approaches to financing and infrastructural problems that hinder the spread of renewable energy technologies. Specifically, the FINESSE program facilitates funding of small-scale energy projects by large-scale multilateral development banks. At the core of the program lies the packaging of renewable energy and conservation projects into financing portfolios of sufficient size to appeal to large lending institutions. The program also identifies and supports representative organizations for these packaged projects (either government, non-government or private organizations) which negotiate directly with the large lending institutions to procure funding.

FINESSE directs financial support to activities which develop technical, political and economic infrastructures to promote the long-term success of energy investments, such as: 1) funding national utilities to purchase and distribute energy-efficient appliances to their urban clients, or to establish mini-utilities in rural areas; 2) supporting and promoting the local manufacture of alternative energy products and services; 3) establishing a franchise system to distribute domestically manufactured systems or components, accompanied by necessary business and technical training; and 4) identifying and supporting the efforts of non-government organizations to work with villages to establish and operate their own renewable energy supply services (such as mini-grids or residential power systems). In addition, FINESSE promotes the incorporation of alternative energies into the pool of conventional power supplies from which governments choose.

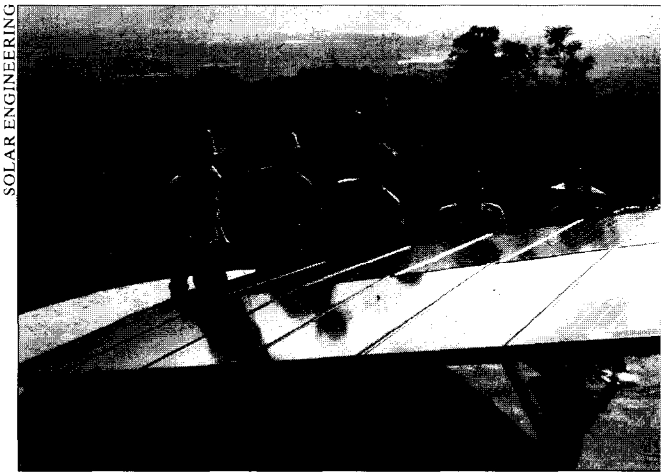
Since 1992, the FINESSE program has concentrated its efforts on Asia, under the direction of the Asia Alternative Energy Unit (ASTAE). Future efforts will focus on Latin America. For more information, contact ASTAE at the World Bank in Washington, D.C.

The future

As photovoltaic production increases and the international market expands, improvements in materials, cell design, and manufacturing offer increasingly efficient and less expensive photovoltaic modules. At the same time, the needs and ingenuity of photovoltaic users and system designers are fostering new and exciting applications of the technology. Some of the more recent endeavors include electric vehicles and the use of photovoltaic-generated electrical current to produce hydrogen fuel from water. More important for developing regions, technologies are emerging that produce clean, potable water from photovoltaic-powered water disinfection and desalinization systems.

With a growing international awareness of photovoltaic technology, its advantages and limitations, and an increasing emphasis on building long-term, sustainable support infrastructures and financing mechanisms, photovoltaics can play a major role in extending basic services to people from all parts of the globe. As the developing world looks for new energy paths, photovoltaics is ready and waiting to serve.

SOLAR ENGINEERING



WATER DISINFECTION: AN EMERGING PHOTOVOLTAIC APPLICATION

This photovoltaic-powered water disinfection system was designed to serve the one thousand villagers of El Volcán, Honduras. The Pan American Health Organization (PAHO) reports that more than 75% of the water supplies in Latin America and the Caribbean are either inadequately disinfected or not disinfected at all. One explanation is that available methods are not suitable for use in rural communities. At PAHO's request, Sandia National Laboratories, Oxi Generators and Solar Engineering collaborated to integrate a photovoltaic power system into the design of an Oxi-2 disinfectant system. The low voltage dc current required by this water disinfection system is an ideal electrical load for photovoltaics. A "mixed-oxidant" electrolysis generator electrolyses salt water to produce chlorine and oxygen oxidants, which kill water-born microorganisms. A 600-watt photovoltaic array mounted on top of the concrete water tank supplies the power necessary to operate this system. The system is integrated into the community's existing gravity-fed water supply, piped from a mountain stream, and can treat more than enough water to fill the 10,000-gallon storage tank each day. Although the photovoltaic system worked well, the mixed-oxidant generator is a fairly new technology and has experienced some operational problems largely related to routine maintenance. However, a simplified mixed-oxidant unit powered by photovoltaics that was recently installed in Tonto National Forest in the western United States is showing promise. This improved technology has fewer operation and maintenance requirements, and may prove more appropriate and reliable for use in remote rural communities. Other similar photovoltaic-powered water disinfection technologies are also entering the marketplace. Local contact: Pan American Health Organization, Apartado Postal 728, Tegucigalpa MDC, Honduras • phone 504-323911 • fax 504-315877. System supplier: Solar Engineering and Oxi Generators.

Glossary

Alternating current (ac): Electric current in which the direction of flow is reversed at frequent intervals; 60 cycles per second is used in the US. This is the current flow from an electric outlet in your home or business.

Ampere-hour (Amp-hour or Ahr): A measure of electrical charge, equaling the quantity of electricity flowing in one hour past any point of a circuit. Battery capacity is measured in amp-hours.

Array: A group of photovoltaic modules wired together to produce a specific amount of power. Array size can range from one to hundreds of modules, depending on how much power will be needed.

Balance of System (BOS): Parts of a photovoltaic system other than the photovoltaic array.

Cell (photovoltaic): A semi-conductor device that converts light directly into dc electricity.

Charge controller: A component of a photovoltaic system that controls the flow of current to and from the battery to protect the batteries from over-charge and over-discharge. The charge controller may also indicate the system operational status.

Concentrator: A photovoltaic module which includes optical components, such as lenses, to direct and concentrate sunlight onto a solar cell of smaller area. Most concentrator arrays must directly face or track the sun.

Direct current (dc): Electric current in which electrons flow in only one direction. This is the current flow produced by a solar system. To be used for typical 120-volt or 220-volt household appliances, it must be converted to alternating current.

Efficiency (of a solar cell or module): The ratio of electric energy produced to the amount of solar energy incident on the cell or module. Typical crystalline solar modules are about 10% efficient — they convert about 10% of the light energy they receive into electricity.

Energy: The capacity for doing work.

Flat-plate module or array: A photovoltaic module or array in which the incident solar radiation strikes a flat surface and no concentration of sunlight is involved.

Grid-connected: A photovoltaic system that is connected to a centralized electrical power network.

Hybrid system: A power system consisting of two or more power generating subsystems (e.g., the combination of a wind turbine or diesel generator and a photovoltaic system).

Insolation: The amount of energy in sunlight reaching an area. Usually expressed in watts per square meter (W/m2), but also expressed on a daily basis as watts per square meter per day (W/m2/day).

Inverter: A device that converts direct current (dc) to alternating current (ac) electricity.

Kilowatt (Kw): 1000 watts.

Kilowatt-hour (Kwh): 1000 watt-hours. A typical residence in the United States consumes about 1000 kilowatt-hours each month at a price in the range of $ .06 to .15 per kilowatt-hour.

Life cycle cost (LCC) analysis: A form of economic analysis to calculate the total expected costs of ownership over the life span of the system. LCC analysis allows a direct comparison of the costs of alternative energy systems, such as photovoltaics, fossil fuel generators, or extending utility power lines.

Load: In an electrical circuit, any device or appliance that uses power (such as a light bulb or water pump).

Maintenance costs: Any costs incurred in the upkeep of a system. These costs may include replacement and repair of components.

Module: A number of solar electric cells wired together to form a unit, usually in a sealed frame of convenient size for handling and assembling into arrays. Also called a "panel".

Operating costs: The costs of using a system. For fuel-based systems these costs include all fuel costs over the system's lifetime.

Parallel connection: A wiring configuration used to increase current (amperage). Parallel wiring is positive to positive (+ to +) and negative to negative (- to -). Opposite of a series connection.

Peak sun hours: The equivalent number of hours per day when solar insolation averages 1000 watts per square meter. For example, six peak sun hours means that the energy received during total daylight hours equals the energy that would have been received had the insolationfor six hours been 1000 watts per square meter.

Peak Watts (Wp): The maximum power (in watts) a solar array will produce on a clear, sunny day while the array is in full sunlight and operating at 25°C. Actual wattage at higher temperatures is usually somewhat lower.

Photovoltaic (PV) system: A complete set of interconnected components for converting sunlight into electricity by the photovoltaic process, including array, balance-of-system components, and the load.

Power: The rate at which energy is consumed or generated. Power is measured in watts or horsepower.

Power conditioner: The electrical equipment used to convert power from a photovoltaic array into a form suitable for subsequent use. Loosely, a collective term for inverter, transformer, voltage regulator, and other power controls.

Renewable energy: Flows of energy that are regenerative or virtually inexhaustible. Most commonly includes solar (electricity and thermal), biomass, geothermal, wind, tidal, wave, and hydro power sources.

Series connection: A wiring configuration used to increase voltage. Series wiring is positive to negative (+ to -) or negative to positive (- to +). Opposite of a parallel connection.

Silicon: A non-metallic element that, when specially treated, is sensitive to light and capable of transforming light into electricity. Silicon is the basic material of beach sand, and is the raw material used to manufacture most photovoltaic cells.

Stand-alone photovoltaic system: A solar electric system, commonly used in remote locations, that is not connected to the main electric grid. Most stand-alone systems include some type of energy storage, such as batteries or pumped water.

Voltage: A measure of the force or "push" given the electrons in an electrical circuit; a measure of electric potential. One volt produces one amp of current when acting against a resistance of one ohm.

Watt (W): A measure of electric power in a unit of time, equal to the rate of flow (amps) multiplied by the voltage of that flow (volts). One amp of current flowing at a potential of one volt produces one watt of power.

Watt-hour (Wh): A measure of electrical energy equal to the electrical power multiplied by the length of time (hours) the power is applied.

Major Development Funding Sources for Renewable Energy Projects

THE WORLD BANK AND RELATED MULTI-LATERAL DEVELOPMENT BANKS

World Bank
Energy Development Division
1818 H Street, N.W.
Washington, D.C. 20433, USA
Phone 202-473-3266/477-1234
fax 202-477-6391
The United Nations created the World Bank by founding the International Bank for Reconstruction and Development (IBRD) in 1945; this was joined by another special UN agency, the International Development Association (IDA), in the mid 1950's. The World Bank works closely with the UN Development Program to finance infrastructure projects in developing countries, and has spawned a number of related programs/projects.

United Nations Development Program (UNDP)
One United Nations Plaza,
New York, NY 10017, USA
Phone 212-906-5000 • fax 212-906-5364
UNDP provides financial and technical support to projects in energy, agriculture, education and other development-related areas, and helped establish the Global Environmental Facility.

Global Environmental Facility (GEF)
(see the World Bank)
The GEF was established by the World Bank in 1990 to support energy-efficiency and new and renewable energy activities that developing countries would otherwise have too little incentive to undertake. It is a cooperative venture between the World Bank, the United Nations Development Program (UNDP), the United Nations Environment Program (UNEP), and national governments.

Energy Sector Management Assistance Program (ESMAP)
(see the World Bank)
Established in 1983 as a joint program of the World Bank and the UNDP. Provides technical assistance on a range of energy issues to recipients of World Bank loans.

Financing Renewable Energy for Small-Scale Energy-Users (FINESSE) (see the World Bank)
The FINESSE project was created by the World Bank's Energy Sector Management Assistance Program (ESMAP) to provide workable approaches to address the financing and infrastructural problems that hinder the spread of the renewable technologies.

International Fund for Agricultural Development (IFAD)
107 Via del Serafico,
00142 Rome, Italy
Phone 39-6-545-91 • fax 39-6-504-34-63
Since 1974, IFAD (a specialized agency of the United Nations) has made low interest loans available directly to poor, small-scale farmers, and to small-medium scale agricultural development projects. Their goals include promotion of food-based rather than export-driven agriculture, and to improve living conditions in rural areas.
International Finance Corporation (IFC)
(See the World Bank). A World Bank private sector affiliate.

Inter-American Development Bank (IDB)
1300 New York Avenue, NW
Energy Division
Washington, D.C. 20577, USA
Phone 202-623-1963 • fax 202-623-3096
A regional branch of the World Bank.

Asian Development Bank
P.O. Box 789
Manila, Philippines 2800
Phone 834-444 or
63-2-711-3851 (international calls)
fax: 632-741-7961
A regional branch of the World Bank.

African Development Bank
01 B.P. No. 1387
Abidjan 01, Ivory Coast
Phone 225-32-07-11
A regional branch of the World Bank.

Caribbean Development Bank
Wildey St. Michael
Barbados
Phone 809-431-1600 • fax 809-426-7269
A regional branch of the World Bank.

BILATERAL ASSISTANCE AGENCIES & PROGRAMS

United States Agency for International Development (U.S.A.I.D.)
Office of Energy
Washington, D.C. 20523, USA
Phone 703-875-4203 • fax 703-875-4053

United States Committee on Renewable Energy (CORECT)
1000 Independence Avenue, SW
Washington, D.C. 20585, USA
Phone 202-586-8302 • fax 202-586-1605

United States Export-Import Bank
811 Vermont Avenue, NW
Washington, DC 20571, USA
Phone 202-566-8802
A U.S. government agency that facilitates the export financing of U.S. goods and services.

International Fund for Renewable Energy and Energy Efficiency (IFREE)
Suite 805,
777 North Capitol Street, NE,
Washington, D.C. 20002, USA
Phone 202-408-7916 • fax 202-371-5115
IFREE fosters environmentally-sound energy projects in developing countries. IFREE was established in 1992 by the U.S. Expert Council for Renewable Energy, in cooperation with the U.S.A.I.D., U.S. Department of Energy, U.S. Environmental Protection Agency and the Rockefeller Foundation.

Canadian International Development Agency (CIDA)
Energy Sector
200 Promenade du Portage
Hull, Quebec, Canada K1A 0G4
Phone 819-997-1492 • fax 819-997-1491

German Agency for Technical Cooperation (Deutsche Gesellschaft fur Technische Zusammenarbeit – GTZ)
Postfach 5180
D-6236 Eschborn 1, Germany
Phone 49-6196-790 • fax 49-6196-791115

Japan International Cooperation Agency (JICA)
Shinjuku Mitsui Bldg, 2-1-1, Nishi-shinjuku,
Shinjuku-ku, Japan
Phone 03-3346-5311-5314
A government sponsored agency which implements a wide range of programs which contribute to the economic and social progress of the developing world. JICA specializes in technical training, consultation, and supplying equipment for technical cooperation internationally.

Swedish International Development Agency (SIDA)
S-10525
Stockholm, Sweden
Phone 46-8-728-5100 • fax 46-8-673-2141

U.S. Suppliers of Photovoltaic Systems for Rural Development

(PARTIAL LISTING)

A.Y. MCDONALD MANUFACTURING COMPANY
4800 Chavenelle Road
PO Box 508
Dubuque, IA 52004-0508, USA
Phone: 319-583-7311 Fax: 319-588-0720
Contact: John D. Eckel, Manager, Energy Products
Systems: PUMPING

ALPHA SOLARCO
11534 Gondola Drive
Cincinnati, OH 45241, USA
Phone: 513-771-1690 Fax: 513-771-5902
Contact: Ed Schmidt
System: CONCENTRATOR SYSTEM

APOLLO ENERGY SYSTEMS, INC.
200 Louise Street
P.O. Box 238
Navasota, TX 77868-0238, USA
Phone: 800-535-8588 Fax: 409-825-2625
Contact: Richard Beardon, General Manager
Systems: PUMPING, LIGHTING

ATLANTIC SOLAR PRODUCTS
9351 J Philadelphia Road
P.O. Box 70060
Baltimore, MD 21237
Phone: 800-537-1566 Fax: 301-686-6221
Contact: Brent Atkins/Doug Keller
Systems: Distributes various systems.

AUTOMATIC GATE SUPPLY CO.
16521 Saticoy Street
Van Nuys, CA 91406, USA
Phone: 800-423-3090 Fax: 818-786-7327
Contact: Keith Naber, Manager
Systems: TRANSPORTATION, SPECIALTIES (PV GATE)

CURRIN CORPORATION
5307 Sturgeon Ave.
PO Box 1191
Midland, MI 48641-1191, USA
Phone: 517-835-7387 Fax: 517-832-8839
Contact: C.G. Currin
Systems: LIGHTING, PUMPING, POWER SYSTEM, SPECIALTIES (FAN)

DIGITAL RECORDERS, INC.
4900 Prospectus Drive
P.O. Box 14068
Research Triangle Park, NC 27709-4068, USA
Phone: 800-222-9583 Fax: 800-849-2947
Contact: Joanne D. Alpiser
Systems: COMMUNICATION

DINH CO., INC.
P.O. Box 999
Alachua, FL 32615, USA
Phone: 904-462-3464 Fax: 904-462-2041
Contact: Khanh Dinh
Systems: REFRIGERATION, PUMPING

ECS
4110 SW 34th Street, Suite 15
Gainesville, FL 32608, USA
Phone: 904-377-8866 Fax: 904-338-0056
Contact: Tom Lane
Systems: POWER SYSTEM

ENERGY CONVERSION DEVICES, INC.
1675 W. Maple Road
Troy, MI 48084, USA
Phone: 313-280-1900 Fax: 313-280-1456
Contact: Nancy Bacon
Systems: LIGHTING

ENTECH, INC.
P.O. Box 612246
DFW Airport, TX 75261, USA
Phone: 214-456-0900 Fax: 214-456-0904
Telex: 265350 ENTECH UR
Contact: O'Neil
Systems: CONCENTRATOR SYSTEM

FLOWLIGHT SOLAR POWER
Rte. 1 Box 216
Española, NM 87532, USA
Phone: 505-753-9699 Fax: 505-753-8474
Contact: Steve Justrich, Marketing Director
Systems: PUMPING

GALLAGHER POWER FENCE
P.O. Box 708900
San Antonio, TX 78270, USA
Phone: 800-531-5908
Contact: Erwin Quinn, President
Systems: SPECIALTIES (PV FENCE)

HARDING CONTROLLED ENERGY
969 - 140th Avenue
Wayland, MI 49348, USA
Phone: 616-792-9410 Fax: 616-792-0211
Contact: David Lankheet
Systems: POWER SYSTEMS

INTEGRATED POWER CORPORATION
7524 Standish Place
Rockville, MD 20855, USA
Phone: 301-294-9133 Fax: 301-294-0809
Telex:79-7799
Contact: Eric Daniels, Director, Marketing
Systems: POWER SYSTEM, COMMUNICATION, HYBRID, CATHODIC PROTECTION & LIGHTING

INTER-ISLAND SOLAR SUPPLY
345 N. Nimitz Highway
Honolulu, HI 96817
Phone: 808-523-0711 Fax: 808-536-5586
Contact: Cully Judd
Systems: Distribute various systems.

JADE MOUNTAIN
P.O. Box 4616
Boulder, CO 80306-4616
Phone: 800-442-1972 Fax: 303-449-8266
Contact: Steve Troy
Systems: Distribute various systems.

K.M. SEED COMPANY
2 Parker Lane,
P.O. Box 929,
Kamuela, Hawaii 96743, USA
Phone: 808-885-7640 Fax: 808-885-4443
Contact: Sales
Systems: SPECIALTIES (ELECTRIC FENCING)

KOPIN CORPORATION
695 Myles Standish Blvd.
Taunton, MA 02780, USA
Phone: 508-824-6696 Fax: 508-822-1381
Contact: Dr. Ron Gale
Systems: CONCENTRATORS

LOS ALAMOS TECHNICAL ASSOCIATION, INC. (LATA)
2400 Louisiana Blvd., NE
Building 1, Suite 400
Albuquerque, NM 87110
Phone: 505-884-3800 Fax: 505-880-3560
Contact: Roger Hoppe
Systems: WATER PURIFICATION

NORTHERN POWER SYSTEMS
One North Wind Road
Moretown, VT 05660, USA
Phone: 802-496-2955 Fax: 802-496-2953
Contact: Woody Stevens
Systems: POWER SYSTEM, CUSTOM LIGHTING, TRANSPORTATION, COMMUNICATION, HYBRID

PARKER-MCCRORY MANUFACTURING CO.
2000 Forest Avenue
Kansas City, MO 64108, USA
Phone: 816-221-2000 Fax: 816-221-9879
Contact: Ken Turner, President
Systems: SPECIALTIES (FENCING)

PHOTOCOMM INC.
7681 East Gray Road
Scottsdale, AZ 85260, USA
Phone: 602-948-8003 Fax: 602-483-6431
Contact: Robert Spotts
Systems: COMMUNICATION, SPECIALTIES (IRRIGATION & BLENDERS), TRANSPORTATION

PHOTOCOMM INC. OF TEXAS
13130 Stafford Road
Stafford, TX 77477, USA
Phone: 713-933-1578 Fax: 713-933-1599
Contact: Kevin Conlin
Systems: LIGHTING, CATHODIC PROTECTION, COMMUNICATION, TRANSPORTATION

POLAR POWER
2808 Oregon Ct., Bldg. K4
Torrance, CA 90503, USA
Phone: 310-320-3514 Fax: 310-320-3135
Contact: Arthur D. Sams
Systems: REFRIGERATION

PREMIER FENCE SYSTEM
P.O. Box 89
Washington, IA 52353, USA
Phone: 319-653-7622 Fax: 319-653-6304
Contact: Douglas R. Bailey, Field Engineer
Systems: SPECIALTIES (FENCING)

SOLAR DEPOT (AKA ENERGY DEPOT)
61 Paul Drive
San Rafael, CA 94403, USA
Phone: 415-499-1333 Fax: 415-499-1306
Contact: Shawn Moshfeghi, Engineer
Systems: POWER SYSTEM (HOME), LIGHTING

REAL GOODS TRADING COMPANY
966 Mazzoni Street
Ukiah, CA 95482, USA
Phone: 800-762-7325 Fax: 707-468-0301
Contact: Doug Pratt, Applications Engineer
Systems: POWER SYSTEM (HOME)

SEA CORPORATION
305 North Mathilda Ave.
Sunnyvale, CA 94086, USA
Phone: 408-720-1804 Fax: 408-720-9405
Contact: Neil Kaminar
Systems: CONCENTRATOR SYSTEMS

SIEMENS SOLAR INDUSTRIES
P.O. Box 6032
4650 Adohr Lane
Camarillo, CA 93011, USA
Phone: 805-482-6800 Fax: 805-388-6395
Contact: Sales
Systems: COMMUNICATION, LIGHTING, POWER SYSTEM, PUMPING

SIMPLER SOLAR SYSTEMS, INC.
3118 W. Tharpe Street
Tallahassee, FL 32303, USA
Phone: 904-5-SOLAR-1 Fax: 904-576-5274
Contact: Al Simpler
Systems: TRANSPORTATION, LIGHTING

SOLAR 4 SYSTEMS
3400 Curtis Drive, Suite 301
Hillcrest Heights, MD 20746, USA
Phone: 301-702-1574 Fax:
Contact: Thelma Cromwell Moss, President
Systems: SPECIALTIES (WATER PURIFICATION)

SOLAR CONTRACTORS INC.
PO Box 37073
Houston, TX 77237-7037, USA
Phone: 713-266-1723 Fax: 405-295-3119
Contact: Sales
Systems: PUMPING

SOLAR ELECTRIC ENGINEERING, INC.
116 4th Street
Santa Rosa, CA 95401, USA
Phone: 800-832-1986 Fax: 707-586-0690
Contact: Alex Kimball, Public Relations
Systems: SPECIALTIES (CAR,VENT,FAN), POWER SYSTEM, TRANSPORTATION

SOLAR ELECTRIC OF SANTA BARBARA
232 Anacapa St.
Santa Barbara, CA 93101, USA
Phone: 805-963-9667 Fax: 805-963-9929
Contact: Scott Williams, Industrial Sales Engineer
Systems: HYBRID, POWER SYSTEMS (RV,MARINE)

SOLAR ELECTRIC SPECIALTIES CO. (SES)
P.O. Box 537
Willits, CA 95490, USA
Phone: 707-459-9496 Fax: 707-459-5132
Contact: Douglas W. Robertson
Systems: CATHODIC PROTECTION, COMMUNICATION, HYBRID, LIGHTING, POWER SYSTEM, PUMPING

SOLAR ELECTRIC SYSTEMS OF KANSAS CITY
2701 Shawnee Mission Parkway
Fairway, KS 66205, USA
Phone: 913-432-6696 Fax:
Contact: Richard V. Collins, Vice President
Systems: LIGHTING, TRANSPORTATION, SPECIALTIES (IRRIGATION)

SOLAR ENGINEERING
1210 Homann Dr. SE
Lacey, WA 98503, USA
Phone: 206-438-2110 Fax: 206-438-2115
Contact: Tim Ball
Systems: POWER SYSTEM (VILLAGE), PUMPING, CUSTOM COMMUNICATIONS & HYBRID

SOLAR OUTDOOR LIGHTING, INC.
3131 S.E. Waaler Street
Stuart, FL 34997, USA
Phone: 407-286-9461 Fax: 407-286-9616
Contact: Steve Robbins, Executive Vice President
Systems: LIGHTING, TRANSPORTATION

SOLAR RETROFIT CONSORTIUM
1040 First Avenue, Suite 354
New York, NY 10022-2902, USA
Phone: 212-754-6137 Fax: 212-355-0817
Contact: Kirk Ludlow
Systems: POWER SYSTEM (HOME), LIGHTING, SPECIALTIES, PUMPING, TRANSPORTATION, REFRIGERATION

SOLAREX CORPORATION
630 Solarex Court
Frederick, MD 21701, USA
Phone: 301-698-4338 Fax: 301-698-4201
Contact: Leonard J. May, Director of Marketing
Systems: POWER SYSTEM, REFRIGERATION

SOLEC INTERNATIONAL, INC.
12533 Chadron Ave.
Hawthorne, CA 90250, USA
Phone: 310-970-0065 Fax: 310-970-1065
Contact: Floyd W. Rutledge, Directory, Sales & Mktg
Systems: LIGHTING, POWER SYSTEM, TRANSPORTATION

SOPHISTICATED SYSTEMS
3785 Alt. 19 North
Palm Harbor, FL 34683, USA
Phone: 813-938-9475 Fax: 813-937-5689
Contact: R. Davidson Keller, Jr., President
Systems: WATER PURIFICATION

SOUTHWEST WINDPOWER
Rt. 8, Box 51
Flagstaff, AZ 86004, USA
Phone: 602-526-0997 Fax:
Contact: Sales
Systems: HYBRID

SUNAMP POWER COMPANY
1902 North Country Club Drive #8
Mesa, AZ 85201, USA
Phone: 602-833-1550 Fax: 602-833-1771
Contact: Dan Washburn, Sales Manager
Systems: CATHODIC PROTECTION, CUSTOM POWER SYSTEM, LIGHTING, REFRIGERATION, TRANSPORTATION, PUMPING

SUNFROST
P.O. Box 1101
Arcata, CA 95521, USA
Phone: 707-822-9095 Fax: 707-822-6213
Contact: Larry Schlussler, Owner
Systems: REFRIGERATION

SUNWIZE ENERGY SYSTEMS, INC.
P.O. Box 191,
Ellenville, NY 12428, USA
Phone: 914-647-6718 Fax 914-647-6828
Contact: Richard Lewandoski, President
Systems: CUSTOM PUMPING

TIDELAND SIGNAL CORPORATION
1994 Eastwood Road
Wilmington, NC 28403, USA
Phone: 919-256-3768 Fax: 919-256-3760
Contact: Victor G. Taylor, Vice President
Systems: LIGHTING, TRANSPORTATION, POWER SYSTEM

TOUCHSTONE TECHNOLOGY
17500 Lemarsh Street
Northridge, CA 91325, USA
Phone: 818-993-9871 Fax: 818-349-8608
Contact: Paul B. Scott
Systems: PUMPING

UTILITY POWER GROUP
Silicon Energy Corporation
9410-G DeSoto Ave.
Chatsworth, CA 91311
Phone: 817-700-1995 Fax: 817-700-2518
Contact: Michael Stern
Systems: POWER SYSTEM

UNITED SOLAR SYSTEMS CORPORATION
1100 W. Maple Road
Troy, MI 48084, USA
Phone: 313-362-4170/3120 Fax: 313-362-4442
Contact: Jim Young, Midwest Sales Manager
Systems: POWER SYSTEM (BATTERY CHARGER)

WIND BARON CORPORATION
3920 E. Huntington Drive
Flagstaff, AZ 86004, USA
Phone: 602-526-6400 Fax: 602-526-5498
Contact: John DePoe
Systems: HYBRID, PUMPING (IN R&D)

Additional Sources of Information

Sources for the following are mentioned in parentheses after the reference when appropriate. See the SOURCES heading for full mailing addresses, phones, contacts, etc.

PHOTOVOLTAIC DIRECTORIES

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Schaeffer, John, et al. *Alternative Energy Sourcebook: 1992.* Ukiah, CA: Real Goods, 1992, (Real Goods – see U.S. SUPPLIERS OF PHOTOVOLTAIC SYSTEMS).

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Wilkins, Paul. *Solar Electricity Today.* (PV Network News, 2303 Cedros Circle, Santa Fe, NM 87505, 505-473-1067, 1992.)

PHOTOVOLTAIC GUIDES

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Stevens, John W., et al. *Photovoltaic Systems for Utilities.* Photovoltaic Systems Design Assistance Center, Sandia National Laboratories, Albuquerque, NM, 1990 (see SOURCES).

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Ventre, Gerard, J.W. Stevens, M.G. Thomas. *Reliable Vaccine Refrigerators: A Comparison of Solar and Kerosene Refrigerators.* SAND88-2434, Photovoltaics Systems Design Assistance Center, Sandia National Laboratories, Albuquerque, NM, 1988, English and Spanish (see SOURCES).

PHOTOVOLTAIC SYSTEM SOFTWARE

F-Chart Software, University of Wisconsin, Solar Energy Laboratory, 4406 Fox Bluff Road, Middleton, WI 53562 USA • ph: 608-836-8536. Offers *PV F-Chart* for photovoltaic system sizing.

Frederick A. Costello, Inc., 12864 Tewksbury Drive, Herndon, VA 22071, USA • ph: 703-620-4942. Offers 10 software packages related to photovoltaic systems.

Photovoltaic Resources International, 1440 W. Meseto Ave., Mesa, AZ 85202, USA • ph: 602-897-6427. Offers PVCAD for photovoltaic system computer aided design.

Photron, Inc., 77 West Commercial Street, Willits, CA 95490, USA • ph: 707-459-3211 fax: 707-459-2165. Offers *SYSTEM-SPEC*, an alternative electrical energy system design software.

Sandia National Laboratories, Photovoltaic Design Assistance Center, Division 6218, Albuquerque, NM 87185-5800, USA • ph: 505-844-3698. Offers: *SIZEPV*, a simulation program for stand-alone photovoltaic systems; and *PVFORM*, a photovoltaic system simulation program for stand-alone and grid-interactive applications.

Solar Energy Laboratory, University of Wisconsin, 1500 Johnson Drive, Madison, WI 53706, USA • ph: 608-263-1589. Offers *TRNSYS-PV*.

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(See SELECTED BIBLIOGRAPHY for additional sources.)

Davidson, Joel and Richard J. Komp. *The New Solar Electric Home.* Second Edition, Ann Arbor, MI: aatec publications, 1987 (library/bookstore).

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Solarex Corp., Technical Staff. *Making & Using Electricity from the Sun.* Blue Ridge Summit, PA: Tab Books, 1979 (Solarex, 1335 Piccard Dr., P.O. Box 6008, Rockville, MD 20850, USA • ph: 301-948-0202)

Strong, Steven. *The Solar Electric House: A Design Manual for Home-Scale Photovoltaic Power Systems.* Emmaus, PA: Rodale Press, 1987 (library/bookstore).

PHOTOVOLTAIC INSTRUCTION

Contact each organization individually for more information.

Electric Systems — Seminar & Workshop. Sunnyside Solar, RD4 Box 808, Green River Road, Brattleboro, VT 05301, USA. One-day program, $95.00.

Energy Systems Photovoltaics Workshop. Photocomm, Grass Valley, CA, USA. One-day seminars, $15.00.

Institute of International Education, Dept. of Science & Technology, 1400 K Street, NW, Washington, D.C. 20005, USA • ph: 202-682-6560, fax: 202-682-6576. Contact Jayne Somers or Sheri Taub for schedule and price of this five-week photovoltaic training course sponsored by the USAID.

North Carolina Solar Center, P.O. Box 7401, NC State University, Raleigh, NC 27695-7401, USA. Contact Bill Brooks for information on solar sessions • ph: 919-737-3480.

Photovoltaic Design and Installation Workshop. Solar Energy International, P.O. Box 715, Carbondale, CO 81623, USA • ph: 303-963-8855 • fax: 303-963-8866. Two-week workshop, $700.00.

Photovoltaic Systems Design Workshop. Florida Solar Energy Center, 300 State Road 401, Cape Canaveral, FL 32920, USA • ph: 407-783-0300. Contact JoAnn Stirling for dates of three-day workshop, $300.00.

Siemens Solar Industries, 4650 Adohr Lane, Camarillo, CA 93011, USA. Contact Mark Mrohs at 805-482-6800, fax: 805-388-6395 for dates and cost of one-week course.

SO-BASEC Workshop. Enersol Associates, 1 Summer Street, Somerville, MA 02143, USA • ph: 617-628-3550, fax: 617-623-5845. Call or write for application and dates of this five-day course in the Dominican Republic, $950.00.

Solar Electric Home Workshop. ME Solar Energy Assoc, Lubic, ME, USA. Contact Marian Lawrence @ 207-773-4711, or Richard Komp @ 207-497-2204.

SunAmp Power Company, P.O. Box 6346, Scottsdale, AZ 85261, USA • ph: 602-833-1550. Two-day course, $175.00.

In addition, several universities sponsor short courses, as well as two- and four-year degree programs focusing on photovoltaic and alternative energy technologies. For a 1992 directory of energy-related graduate programs in the USA, contact *Home Energy* at 2124 Kittridge Street #95, Berkeley, CA 94704, USA • ph: 510-524-5405.

SOURCES FOR DOCUMENTS, TECHNICAL & INDUSTRY INFORMATION

American Solar Energy Society, 2400 Central Ave., B-1, Boulder, CO 80301, USA • ph: 303-443-3130 (United States section of the International Solar Energy Society).

Canada Centre for Mineral & Energy Technology, Energy Mines and Resources Canada, 580 Booth Street, Ottawa, Ontario K1A OE4, Canada. Contact Rudy Rubin, ph: 613-996-9416 • fax: 613-996-9416.

Commonwealth Science Council, Marlborough House, Pall Mall, London SW1Y 5HX, England.

Conservation and Renewable Energy Inquiry and Referral Service (CAREIRS), P.O. Box 8900, Silver Spring, MD 20907, USA • ph: 800-523-2929.

Danish Renewable Energy Organization (OVE), Willemoesgade 14, 2100 Kobenhavn 0, Denmark • ph: 45-3142-9091 • fax: 45-3142-9095.

Florida Solar Energy Center, Public Information Office, 300 State Road 401, Cape Canaveral, FL 32920, USA • ph: 407-783-0300 • fax: 407-783-2571. Contact Betsy Pesce.

German Solar Energy Center (Bundesverband Solarenergie - BSE), Krupstasse 5 • D-4300 Essen 1, Germany.

International Solar Energy Society (ISES), P.O. Box 124, Caulfield East, Vic. 3145, Australia • ph: 61-3-571-7557 • fax: 61-03-563-5173.

IT Power Ltd. The Warren, Bramshill Road, Eversley, Hants, RG27 OPR, United Kingdom • ph: 44-734-730073 • fax: 44-734-730820.

Maycock, Paul. PV Energy Systems, P.O. Box 290, Casanova, VA 22017, USA • ph: 703-788-9626.

Meridian, 4300 King Street, Suite 400, Alexander, VA 22302, USA • ph: 703-998-3705 • fax 703-998-0887. Contact Chris Rovero for publications.

National Appropriate Technology Assistance Service (NATAS), P.O. Box 2525, Butte, MT 59702, USA • ph: 800-428-2525.

National Renewable Energy Laboratory (NREL, formerly SERI), Technical Inquiry Service, 1617 Cole Blvd., Golden, CO 80401, USA • ph: 303-231-7303. Contact Steve Rubin for publications.

NTIS, U.S. Dept. of Commerce, 5285 Port Royal Road, Springfield, VA 22161, USA • ph: 703-487-4650.

Sandia National Laboratories, Design Assistance Center, Division 6218, P.O. Box 5800, Albuquerque, NM 87185, USA • ph/fax: 505-844-3698. Contact Peggy Valencia for documents.

Solar Electric Light Fund (SELF), 1739 Connecticut Ave., Washington, D.C. 20009, USA • ph/fax: 202-234-7265. Contact Neville Williams for documents.

Solar Energy Industries Association (SEIA), 777 W. Capitol Street N.E., Suite 805, Washington, D.C. 20002, USA • ph: 202-408-0660.

Stockholm Environment Institute, P.O. Box 2142, S-103 14 Stockholm, Sweden • ph: 46-8-723-0260 • fax: 46-8-723-0348.

The World Bank/The International Bank for Reconstruction and Development, 1818 H Street, NW, Washington, D.C. 20433, USA • ph: 202-473-3266.

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Asian Pacific Development Center. *Financing Energy Services for Small-Scale Energy Users (FINESSE).* Proceedings of the Regional Workshop on Financing of Energy Services for Small Scale Energy Users, 21-25 October 1991, Kuala Lumpur, Malaysia, 1992.

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NOTES

* U.S. GOVERNMENT PRINTING OFFICE 1993 573-110/80281